CLIMATE CHANGE
Climate Science and the Stern Review

Robert M. Carter, C. R. de Freitas, Indur M. Goklany, David Holland & Richard S. Lindzen

Introduction

In Part I of the Dual Critique[1] of the Stern Review, hereafter C2006, we disputed its presumption that the "Earth's climate is rapidly changing, mainly as a result of increases in greenhouse gases caused by human activities".[2] We pointed to the excessive reliance on computer models in preference to observations. We questioned why what is presented as the greatest problem facing humankind was in part based upon science for which data disclosure has not been made, and pointed to the inadequacy of the peer review process in guaranteeing the quality and reproducibility of scientific contributions.

Our critics seem unable to shake themselves free of a fierce conviction, aptly expressed by Heller (p. 107),[3] that climate change is "… for real, … anthropogenic in nature, and that lingering uncertainties on the likely magnitude of changes over the next century have been sharply reduced".

Robert M. Carter is a Research Professor at James Cook University, Queensland and the University of Adelaide, South Australia. **C. R. de Freitas** is a climate scientist in the School of Geography, Geology and Environmental Science at the University of Auckland. **Indur M. Goklany** is a science and technology policy analyst at the US Department of the Interior. (Views expressed in this paper are the author's and not the US government's.) **David Holland** is an engineer, and a member of the Institution of Engineering and Technology. **Richard S. Lindzen** is the Alfred P. Sloan Professor of Atmospheric Sciences at the Massachusetts Institute of Technology.

[1] Carter, R. M., C. R. de Freitas, I. M. Goklany, D. Holland, and R. S. Lindzen (2006), 'The Stern Review: A Dual Critique—Part I: The Science', *World Economics*, **7** (4): 167–198.
[2] The Stern Review, Key Message, p. 2.
[3] Heller, P. S. (2007), 'Addressing Climate Change: Is There a Role to be Played by the IMF?', *World Economics*, **8** (1): 107–120.

That human-caused climate change is real has never been in question; the point at issue is whether the global signal of human-caused change can be measured, and, if so, whether the resulting effect is likely to be dangerous. After the expenditure of many tens of billions of dollars on cognate research, the answer to these questions is that the global human signal cannot be isolated from the variation of the natural climate system itself, and that—speculative computer modelling aside—no good reason exists to presume that the human impact is dangerous. Basing economic analysis on such flawed scientific assumptions, as Heller and others do, does not augur well for the usefulness and validity of any conclusions that may be reached. Wrong science breeds pointless economics; it's that simple.

What follows is a response to the comments principally from Mitchell *et al.*[4] and Arnell *et al.*,[5] hereafter M2007 and A2007. M2007 (p. 222) posit at the outset that "It is not sufficient for C2006 to argue that there is a possibility that future climate change might be small and hence the risks negligible unless they can prove that this is the case". Our main argument, however, was not that future climate change will be small (though it might be), nor that the risks of natural climate change are negligible, but rather that we don't know either the magnitude of any human causation, particularly that due to greenhouse gas emissions, nor the future direction that net climate change will follow. We agree with Mitchell *et al.* and others that the key issue is assessment of risk, but that includes the risk of future coolings as well as warmings. This is why an adaptive policy towards climate change is the most sensible option, especially since many adaptation options would reduce many of today's urgent climate-sensitive problems whose existence is in no doubt, e.g., hunger, vector-borne diseases, water stress, and extreme weather events.[6] No less important, the benefits of such adaptation policies would be much higher than any climate change mitigation policy through 2085 and, most likely, beyond because the contribution of non-climate change related factors to these problems should generally outweigh that of climate change according to many global impacts studies sponsored by the UK Department for Environment, Food

[4] Mitchell, J., J. Slingo, D. S. Lee, J. Lowe, and V. Pope (2007), 'Response to Carter et al.', *World Economics*, **8** (1): 221–228.
[5] Arnell, N., R. Warren, and R. Nicholls (2007), 'Response to 'The Stern Review: A Dual Critique', *World Economics*, **8** (1): 229–231.
[6] Goklany, I. M. (2005), 'A Climate Policy for the Short and Medium Term: Stabilization or Adaptation?', *Energy & Environment*, **16**: 667–680.

and Rural Affairs (DEFRA) which, moreover, were used extensively in the Stern Review.[7] Furthermore, it is not for us to "prove our case" any more than it is the Intergovernmental Panel on Climate Change (IPCC)'s duty to prove theirs. One might just as well write "It is not sufficient for Mitchell *et al.* to argue for mitigation measures just because computer models suggest future warming unless they can prove that cooling won't occur". That, of course, is not the way that science operates. Rather, it is incumbent on all involved in the climate debate to examine the data dispassionately, and then follow them wherever they may lead.

Business as usual

The comments that M2007 make on our paper follow the well worn path of urging readers to accept that the science of global warming is settled and move on to the more important and, of course, far more expansive and interesting areas of the "the possible range of future warming" which M2007 consider more important and the "impacts" with which the Stern Review was principally concerned. In their opening sentence, "Those who deny the importance of strong and urgent action on climate change essentially offer one of, or a combination of, the following arguments.", Dietz *et al.*,[8] hereafter D2007, signal their attitude to dissent, by the word "deny". None of the three arguments they go on to mention fits the position taken by C2006. The two references[9,10] chosen by D2007 to support the assertion that the science is settled and that those who question it are "reckless" contain the same old arguments for which we have already provided a reasoned critique. Published with glossy forewords by Tony Blair and Margaret Beckett, Hans Schellnhuber's book, *Avoiding Dangerous*

[7] A synthesis of these DEFRA-sponsored studies is available in: Goklany, I. M. (2007), 'Adaptive Management of Climate Change Risks', in: *A Breath of Fresh Air: Market Solutions for Improving Canada's Environment,* Fraser Institute, Vancouver, Canada, available at http://www.fraserinstitute.ca/admin/books/files/AdaptiveManagementUpdate.pdf. Note that the Stern Review used these studies to help estimate the impact of climate change on various climate-sensitive problems (e.g., malaria, hunger, coastal flooding, and water stress) but overlooked the fact that these same studies also indicated that the contribution of climate change to these problems is, for the most part, relatively small compared to other non-climate-change related factors through the studies' time horizon (generally 2085).

[8] Dietz, S., C. Hope, N. Stern, and D. Zenghelis (2007), 'Reflections on the Stern Review (1): A Robust Case for Strong Action to Reduce the Risks of Climate Change', *World Economics*, **8** (1): 121–168.

[9] Schellnhuber *et al.* (eds.) (2006), *Avoiding Dangerous Climate Change*, Cambridge University Press. Available at http://www.defra.gov.uk/environment/climatechange/internat/dangerous-cc.htm

[10] IPCC (2007), *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Solomon *et al.* (eds.), Cambridge University Press, Cambridge, UK and New York, NY, USA. (Available at http://www.ipcc.ch/)

Climate Change, does no more than repeat the assertion from the IPCC Third Assessment Report of 2001 that "attribution by exclusion" proves human causality of recent climate change. Though published in 2006 it still treated the "hockey stick" study of Dr Michael Mann as unquestioned, while the Stern Review at least acknowledged the growing doubts that have now invalidated it.

Corroboration

M2007 say that the IPCC (2007) Summary for Policymakers (hereafter SPM) "corroborates the scientific basis of the Stern Review." Given the reliance of the Stern Review on UK Climate Research bodies and their involvement in the IPCC process,[11] it would be surprising if that were not the case to some extent. However, in nuance, IPCC (2007) is less alarmist and Sir Nicholas Stern appears to admit this in his recent BBC radio interview[12] in saying, "The IPCC is a good process, but it has to depend on consensus. It means that they have to be quite cautious in what they say". Stern himself, in contrast, is often much less cautious. For instance on the science, the Stern Review made the unambiguous and alarming claim on p. 5 [emphasis added]:

> Over the past 30 years, global temperatures have risen rapidly and continuously at around 0.2°C per decade, bringing the global mean temperature *to what is probably at or near the warmest level reached in the current interglacial period*, which began around 12,000 years ago.

Note that this statement does not limit itself to the Northern Hemisphere or explain what "probably" means in this context. In support of this view, the Stern Review cited Hansen *et al.* (2006)[13] published only weeks before the Review itself, a paper that was not cited by IPCC (2007) Working Group I (hereafter WGI) whose cut off date for papers was December 2005. The IPCC do allow for exceptions to their cut off dates and could certainly have used Hansen's paper had they judged it to be useful. Even

[11] The list of lead authors and review editors of IPCC (2007) Working Group I numbers 169 of which, at 39, the USA provides the largest contingent followed by the UK at 18, which is the largest contingent in per capita terms.
[12] BBC Radio 4, *The Investigation*, Thursday 25 January 2007 at 2000 GMT.
[13] Hansen, J., M. Sato, R. Ruedy, K. Lo, D. W. Lea, and M. Medina-Elizade (2006), 'Global Temperature Change', *Proceedings of the National Academy of Sciences*, **103** (39): 14288–14293.

more to the point, however, Hansen *et al.* (2006) is a single, essentially unreviewed, study which other studies contradict—for example, that of Keigwin.[14] In the IPCC (2007) WGI Chapter 6, for which Dr Mitchell was one of the two review editors, the IPCC did however cite one unpublished (as at 4th June 2007) and controversial paper from two other scientists, in order to bolster the preferred view of unusual warming, viz.:

> Palaeoclimatic information *supports the interpretation* that the warmth of the last half century is *unusual* in at least the previous 1,300 years. [emphasis added][15]

The global claim made in the Stern Review is absent from IPCC (2007) because of a lack of scientific evidence to make it. The phrase "supports the interpretation" is not one the IPCC attach any probability to and merely demonstrates the reluctance of the IPCC to face up to (or use their discretion to cite) the conclusions of the National Research Council,[16] which were [emphasis added]:

> Largescale temperature reconstructions should always be viewed as having a "*murky*" early period and a later period of relative clarity. The boundary between murkiness and clarity is not precise but is nominally around *A.D. 1600*.

As to the Stern Review's glib claim that global temperature has increased over the past 30 years at a continuous rate of about 0.2°C per decade, we can only wonder how this is reconciled with the Hadley Centre's observation that this quantity has changed by less than 0.05°C over the past decade—a change well within the uncertainty of the data. It should be noted that we have ignored the fact that 1998 was distinctly warmer than 2006, since 1998 is associated with a strong El Niño event. However, even discounting this peak leads to no statistically significant warming over the last eight years; including it results in the delineation of a cooling trend. Hamid *et al.*[17] diverge even further, saying on p. 184, "We are already locked into the next 20–30 years of climate change of between

[14] Keigwin, L. D. (1996), 'The Little Ice Age and Medieval Warm Period in the Sargasso Sea', *Science*, **274**: 1504–1508.
[15] IPCC (2007) SPM, p. 9.
[16] National Research Council, Committee on Surface Temperature Reconstructions for the Last 2,000 Years (2006), *Surface Temperature Reconstructions for the Last 2,000 Years*, National Academies Press, Washington, DC, USA.
[17] Hamid, L., N. Stern, and C. Taylor (2007), Reflections on the Stern Review (2): A Growing International Opportunity to Move Strongly on Climate Change', *World Economics*, **8** (1): 169–186.

1 to 2 degrees increase in average global temperatures". The equivalent IPCC (2007) projection[18] is between 0.2 and 0.6°C.

A fundamental scientific dispute

At the root of what M2007 and D2007 want us all to accept as 'settled science', and from which all their alarming forecasts flow, is that substantial positive feedback amplifies the warming that results from any increase in greenhouse gases in the atmosphere. Their conjecture is that the warming itself causes an increase in the amount of water vapour in the atmosphere. Water vapour is the most powerful of all greenhouse gases and its increase causes yet more warming. In addition, in the most sensitive models, clouds (another major greenhouse substance) also change so as to provide positive feedback. The increase, or amplification, obtained is not modest but from 2.5 to 5 times the intrinsic warming caused by an increase of CO_2 alone, which, for the benchmark doubling of CO_2, is shown, by relatively uncontroversial physics, to be about 1°C. We argued that observations of CO_2 increases and surface temperature over the last century do not support this hypothetically enhanced warming but point to warming much nearer the intrinsic value—if not less.

M2007 claim that we did not experience the full warming effect of CO_2 emissions last century because aerosols reduced it and the oceans delayed it. However in Figure SPM.2, IPCC (2007)[19] still rates aerosols as medium to poorly understood. The same figure shows that the current aerosol cooling that M2007 state as 1.2 W m^{-2} could be as little as 0.4 W m^{-2}. Indeed, leading aerosol scientists regard this degree of confidence to be generous and this is yet another area of climate science where observations are at odds with theory. Aerosols are mostly emitted in the northern hemisphere, where most industry is located, and have a short residency in the atmosphere. We would therefore expect the northern hemisphere to be warming less quickly than the southern hemisphere. But both the surface data and the satellite data show the opposite. In fact, the satellite data since 1979 show the southern hemisphere temperature to be quite stable.

[18] For the next two decades, a warming of about 0.2°C per decade is projected for a range of SRES emission scenarios. Even if the concentrations of all greenhouse gases and aerosols had been kept constant at year 2000 levels, a further warming of about 0.1°C per decade would be expected. IPCC (2007) SPM, p. 12.
[19] IPCC (2007) SPM, p. 4, Figure SPM.2.

The ocean delay argument is equally questionable and depends critically on both the sensitivity of the climate model and the thermal diffusivity assumed by the model for the oceans. The reasons for this behavior are not hard to explain. Climate sensitivity is essentially a ratio of a change in temperature to a radiative forcing. In a sensitive climate, a large temperature is associated with a small forcing. The forcing, however, determines the rate at which the ocean temperature changes. For a given temperature change, this rate will be smaller the more sensitive the climate. The thermal diffusivity determines how deeply the heat must penetrate. The higher the diffusivity, the deeper the ocean layer that needs to be heated. As we will show, there are independent reasons to believe that current models are exaggerating climate sensitivity; it is also commonly noted that models use larger diffusivities than can be justified from observations.[20] Thus, the appeal to ocean delay is dubious at best.

M2007 do not say what sensitivity their arguments imply for the observed rise in the 20th century temperature, but it is difficult to see how they could reach an amplification of 2, let alone 5, based on observations. There are, however, other observations that cast serious doubt on the supposedly 'settled science'. What follows tests the hypothesis of feedback enhanced global warming against more fundamental observations.

Oversimplifications

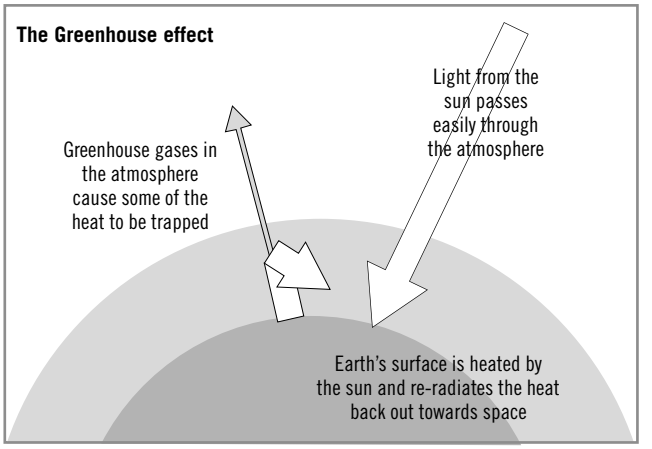
In science, complex systems often have to be simplified or they cannot be analysed. Yet if they are oversimplified the analysis may be meaningless. This commonly applies to the case in dispute.

The theory of global warming is usually presented with a simplified radiative forcing diagram of which Figure 1 is an example.[21] The cooling of the earth by thermal radiation from the surface is shown on the left of the diagram. However, there is something seriously wrong with this oversimplified picture. Namely, the surface of the earth does not cool primarily by thermal radiation. The situation is more nearly akin to the

[20] Willis, J. K., D. Roemmich, and B. Cornuelle (2004), 'Interannual Variability in Upper Ocean Heat Content, Temperature, and Thermosterisc Expansion on Global Scales', *Journal of Geophysical Research*, **109**, C12036; Schmitt, R. W., J. R. Ledwell, E. T. Montgomery, K. L. Polzin, and J. M. Toole (2005), 'Enhanced Diapycnal Mixing by Salt Fingers in the Thermocline of the Tropical Atlantic', *Science*, **308**: 685–688; Merrifield, B. (2005), 'Ocean Mixing in 10 Steps', *Science*, **308**: 641–642.

[21] http://www.bnsc.gov.uk/lzcontent.aspx?nid=4804

Figure 1: Greenhouse warming simplified

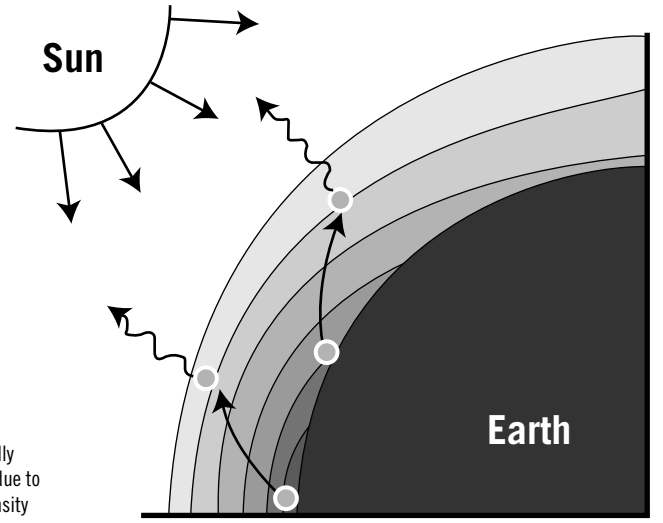


schematic shown in Figure 2. The main greenhouse gas, water vapour, generally has maximum effect at the surface in the tropics and sharply decreases with both altitude and latitude. The dark belt shown in Figure 2 has a large effect at low latitudes, and the lighter belts diminishing effect at high latitudes and altitudes. There is so much greenhouse opacity immediately above the ground that the surface cannot effectively cool by the emission of thermal radiation. Instead, heat is carried away from the surface by fluid motions ranging from the cumulonimbus towers of the tropics to the weather and planetary scale waves of the extratropics. These motions, shown by the solid lines in Figure 2, carry the heat upward and poleward to levels where it is possible for thermal radiation emitted from these levels to escape to space, shown by the wavy line. In this fuller explanation it is less obvious that the added water vapour and indeed CO_2 will act so as to increase global warming at the surface. It must be remembered that it is these greenhouse gases at high altitude that actually cool the Earth's atmosphere.

A more detailed explanation[22] of the way the Earth cools is beyond the scope of this response, but it is the case that there is a level, sometimes

[22] Lindzen, R. S. (1990), 'Some Coolness Concerning Global Warming', *Bulletin of the American Meteorological Society*, **71**: 288–299.

Figure 2: More realistic depiction of how the earth's surface cools



called the 'characteristic emission level' in the troposphere, 7–8 km in the tropics and lower towards the poles, from which the atmosphere effectively radiates back into space. This is shown in Figure 2 as the endpoints of the non-wavy parts of the arrows. It is the temperature at these levels that determines the radiative cooling that must balance solar heating. When greenhouse gases are added to the atmosphere, the emission level is elevated to altitudes that are cooler. Therefore, less radiative cooling occurs and there is no longer a balance with solar heating. This imbalance is what is generally referred to as radiative forcing. In order to reestablish balance, this new level must warm, and it is this warming that is the fundamental warming associated with the climate "greenhouse" effect (to distinguish it from plant greenhouses which operate in a very different manner). How warming at the emission level relates to warming at the surface is not immediately self-evident. It is at this point that models prove helpful.

Lee *et al.* (2007)[23] showed how temperature changes when CO_2 is doubled in four rather different General Circulation Models (GCMs).

[23] Lee, M.-I., M. J. Suarez, I.-S. Kang, I. M. Held, and D. Kim, 2007: 'A Moist Benchmark Calculation for the Atmospheric General Circulation Models', *Journal of Climate*, in press.

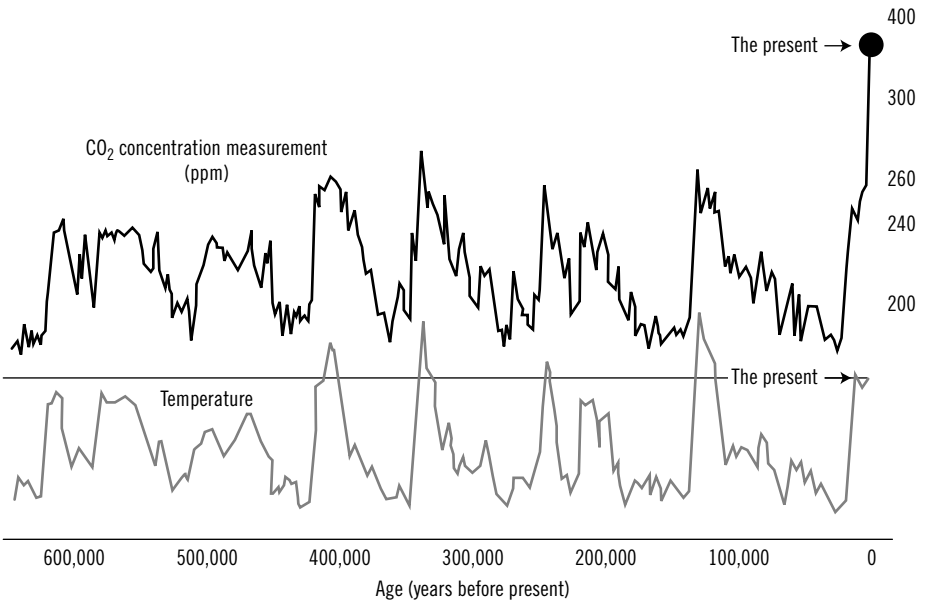
Roughly speaking the warming at the high altitude emission levels in the tropics is from two to three times larger than at the surface regardless of model sensitivity, which varied substantially among the four models. We have good observational measurements of the temperature of this area of the troposphere since at least the 1960s and the trend is about three-quarters the trend at the surface—*not* 2–3 times larger as shown by the models. Moreover, according to the models, only about 40% of the upper level warming can represent greenhouse warming at the surface. Thus, only about 30% of the warming at the surface can be due to greenhouse warming. From this we can conclude that unless the models are fundamentally wrong, or unless the recent increase in surface temperature is exaggerated, or unless the observed trends in the tropical upper troposphere are greatly understated, substantial greenhouse warming has not occurred. This is but one reason why the data and methodology of the globally averaged surface temperature series and results of related urban heat island studies should be open to critical examination.

There is a further way in which observations dispute the alarmist paradigm. In a remarkable politicisation of the UK's education system, David Miliband, Secretary of State for Environment, Food and Rural Affairs, is proposing to send a copy of Al Gore's award winning film, *An Inconvenient Truth*, to every school in England. If the science teachers are as good as they used to be they will pause at the Antarctic Ice Core scene shown as Figure 3.[24] After pointing out that correlation is not the same as causation, three simple observations should be made that do not depend upon complex discussions of aerosols or oceans:

1. It is easily seen that in the past, when temperature fell, it did so long before the CO_2 concentrations. Higher resolution work of Severinghaus and Brook[25] also shows that in the deglaciation period temperature rose hundreds of years before concentrations of CO_2 followed. This is not consistent with CO_2 causing the change in temperature.

[24] Gore had previously used a core from the Vostok station, but this core ended at 420 thousand years ago when it reached a subterranean lake. The current core is from Dome C, about 500km from Vostok.
[25] Severinghaus, J. P., and E. J. Brook (1999), 'Abrupt Climate Change at the End of the Last Glacial Period Inferred from Trapped Air in Polar Ice', *Science*, **286** (5441): 930–934.

Figure 3: Atmospheric carbon dioxide levels and temperatures inferred from the Vostok ice core. From Al Gore's *An Inconvenient Truth* (2006)



Source: *Science Magazine*

2. Significantly, the Antarctic ice cores also show that the preceding four interglacials were warmer than now, yet exhibit lower levels of CO_2—a fact that further weakens the argument of CO_2 causation.
3. It can be seen in the ice cores that CO_2 varies from about 180 to 280 ppm, which in radiative forcing terms is equivalent to a little over half the change of what one would get from a doubling of CO_2 from preindustrial values. The change in temperature shown in Figure 3 is about 10°C, which is estimated to be about double the change in global mean temperature (Hansen and Sato, 2004).[26] Now, the most sensitive models cited by the IPCC yield about 4.5°C for a doubling of CO_2 or about 2.5°C for the changes in CO_2 shown in Figure 3. Thus, if CO_2 were the causal factor, the sensitivity of the Earth's climate to CO_2 would have to be about twice as large as the sensitivity of the most sensitive current

[26] Hansen, J., and M. Sato (2004), 'Greenhouse Gas Growth Rates', *Proceedings of the National Academy of Sciences*, **101**: 16109–16114.

model. However, as recently shown by Rodwell and Palmer (2007)[27] and by Annan *et al.* (2005),[28] the current models with high sensitivity are extremely improbable. Thus, it is virtually impossible for CO_2 to have caused the temperature changes associated with the Antarctic climate changes, though they may have contributed somewhat to the magnitudes.

Feedbacks

M2007 incorrectly claim on p. 223 that, in C2006, we argued "that the changes in cloud cover and water vapour that accompany the warming, would act to cool the climate—a negative feedback". What C2006 actually say, discussing one possible mechanism, is "The process (sometimes referred to as the Iris Effect), it should be noted, would reduce sensitivity to a doubling of CO_2 to less than 0.5 degrees C—rather more consistent with observations."

The point here is that our approach is consistent with observations. However, later on the same page M2007 say "Determining cloud feedbacks from observations of natural variations in climate remains difficult, but modelling studies indicate that clouds give anything from a small negative feedback to a strong positive feedback, with the most likely effect being positive." Once again we see the results of model studies being preferred to observations, indeed it almost sounds like the models are now able to prove themselves to be right. Is it mere happenstance that alarming predictions depend upon positive feedback?

It is possible for all systems to have within them subsystems that demonstrate positive and others that demonstrate negative feedback. Positive feedback, however, is inherently unstable and the comparative stability of the climate within a narrow temperature range over long periods of time is more consistent with an overall negative feedback, as inferred also for late 20th century temperature records by Karner (2002).[29]

---

[27] Rodwell, M. J., and T. N. Palmer (2007), 'Using Numerical Weather Prediction to Assess Climate Models', *Quarterly Journal of the Royal Meteorological Society*, **133** (622): 129.
[28] Annan, J. D., J. C. Hargreaves, R. Ohgaito, A. Abe-Ouchi, and S. Emori (2005), 'Efficiently Constraining Climate Sensitivity With Paleoclimate Simulations', *SOLA*, **1**: 181–184.
[29] Karner, O. (2002), 'On Non-Stationarity and Anti-Persistency in Global Temperature Signatures', *Journal of Geophysical Research*, **107**, D20. http://www.aai.ee/~ol-avi/2001JD002024u.pdf.

Models

With the emphasis on modelling in the Stern Review and IPCC (2007)[30] it is not surprising that M2007 disapprove of our critical comments in C2006 on models. With the downgrading in IPCC (2007) of the "hockey stick" as the "smoking gun" of climate change, the models and the global surface temperature series are being emphasised more. M2007 (p. 222) attempt to explain away our comment that the observed climate change response to date is much smaller than climate models predict. After discussion of non-greenhouse factors such as aerosols and heat storage in the ocean, they conclude that "if these factors are taken into account, then the observed warming may be reconciled with the observed increases in greenhouse gas concentrations and aerosols, and is consistent with the range of sensitivity of climate to greenhouse gases reported in [IPCC (2007)]". This type of argument is much favoured by those who believe that computer attribution studies can be used as "evidence for" human-caused climate change. Yet, as von Neumann famously remarked about such curve-fitting exercises many years ago, "With four parameters I can fit an elephant, and with five I can make him wiggle his trunk". Given the millions of degrees of freedom in all GCMs, it is scarcely surprising that the climate elephant can be trained to perform double pikes and handstands as well.

Therefore, the confidence that M2007 place on GCM modelling—including especially its claims that the models are based on physics, are "not adjusted" and are reliable—need to be treated with great caution. Beginning with the fact that the numerical methods are uncertain approximations to the underlying equations, and continuing to the fact that these approximations cannot even resolve crucial components like clouds and fronts, we are clearly very far from a simple application of basic physics. Models are, of course, extensively and very successfully used in all areas of research and industry. Modern petrol-driven cars have models built into their computerised engine management systems. Despite having the actual engines, which are far simpler than the climate, available to analyse and test, these models are expensive to develop and, even after extensive testing, often have to be upgraded in the field.

[30] There are more than 9,000 instances of 'model', 'simulate' and their derivatives in IPCC (2007) WGI.

In one sense all models predict the future, even if in the case of engine management it is only for fractions of a second ahead. The forecasting reliability of all models has to be tested against reality. Engine management models are now often adaptive, their predictions being constantly checked by the reality as measured by the HEGO (heated exhaust gas oxygen) sensors. Weather forecast models have only achieved their current, still limited, reliability through refinement as we see the reality the model is forecasting each day. Climate models are fundamentally different in that we have to wait a very long time to see if they are right. While there will have been some improvements in techniques since 2001, it is still worth reminding readers what Professor North of the Department of Atmospheric Sciences at Texas A&M said:[31]

> There are so many adjustables in the models and there is a limited amount of observational data, so we can always bring the models into agreement with the data.

That the models simulate the last decades of a comparatively linear trend and forecast only linear trends into the future is not a great comfort. Relying on their ability to replicate the previous cooling trends from 1940 to about 1965 is compromised by the lack of accurate data on solar variability and atmospheric aerosol loading from both industry and volcanoes prior to the 1960s. M2007 take exception to our suggestion that aerosols are treated in the models in a circular way, but we are hardly alone in observing this. The most prominent members of the aerosol community noted (Anderson *et al.*, 2003)[32] that uncertainty over the properties of aerosols was so great that using values that yielded reasonable model simulations was not implausible, but that to use such values to test the models was indeed circular. The uncertainty in solar forcing that M2007 refer to is irrelevant to this matter. Besides the references we gave and what IPCC (2007) says, it is worth noting the view of Dr Myles Allen of the Climate Dynamics Group at Oxford University. Dr Allen was an initiator of the Climateprediction.net project and in lectures during 2005 used a presentation,[33] "How much carbon can we emit?". The fifth slide is

[31] Kerr, R. A. (2001), 'Global Warming: Rising Global Temperature, Rising Uncertainty', *Science*, **292**: 192.
[32] Anderson, T. L., R. J. Charlson, S. E. Schwartz, R. Knutti, O. Boucher, H. Rhode, and J. Heintzenberg (2003), 'Climate Forcing by Aerosols—A Hazy Picture', *Science*, **300**: 1103–1104.
[33] http://www.ukerc.ac.uk/component/option,com_docman/task,doc_download/gid,334

entitled "Large uncertainty in greenhouse warming to date because of uncertainty in aerosol cooling".

Whether it is called adjustment or refinement, the iterative improvement by small extensions to their verified range is common to all modelling techniques. Otherwise one has to wonder why so much is spent on climate models if they are perfect already. Two other views of people involved in modelling are instructive. Science is well tested when it is put to work commercially. Jerome Schmitt is president of NanoEngineering Corporation, has worked in the process equipment and instrument engineering industries for nearly 25 years and has described[34] his experiences with process models. Of climate models and their many variables, he says [emphasis added]:

> Even if mathematics could be developed to accurately model each of these factors, the combined model would be infinitely complex *requiring* some simplifications. *Simplifications in turn amount to judgment calls by the modeler.*

Over Christmas 2006, the National Environmental Research Council challenged the world's sceptics to debate climate science with them on the Internet and many accepted the invitation. The debate soon focused on models and, in answer to post number 66 from Timo Hämeranta of Finland, NERC's Chief Executive, Dr Alan Thorpe, said [emphasis added]:[35]

> The size of the recently observed global warming, over a few decades, is significantly greater than the *natural variations in long simulations with climate models* (if carbon dioxide is kept at pre-industrial levels). Only if the human input of greenhouse gases is included does the simulated climate agree with what has been recently observed.
>
> *Measurements prior to the modern instrumented record are probably insufficiently frequent and detailed to say whether such a global warming over a few decades has occurred before.* However in any case, the real issue is whether human activity is causing the current warming because, if so, then we are able to do something about it.
>
> Climate models *attempt to include all the natural factors that might lead to significant climate variations* on the timescales of interest, i.e. years to decades to centuries. *Clearly factors currently unknown to science can't be included, but we have no reason to suppose they exist.*

[34] http://www.americanthinker.com/printpage/?url=http://www.americanthinker.com/2007/02/numerical_models_integrated_ci.html
[35] http://www.nerc.ac.uk/about/consult/debate/debate.aspx?did=1&pg=30

In the last sentence of his comment, Dr Thorpe reveals the unjustifiable confidence that causes those of us who question the models so much concern. Do climate modellers really believe we have reached the end of scientific discovery rather like Fukuyama announced the end of history? Dr Thorpe's comments may have been unguarded, but it is significant that M2007 say much the same on p. 225:

> It is only possible to attribute 20th Century warming to human interference using numerical models of the climate system.

This statement may be literally true but is more a comment on the limitations of models and not evidence (and still less proof) of human interference with the climate.

Peer review and disclosure

On its first page, M2007 dismiss our concerns over the brazen refusal of some scientists to disclose the data and methods used on some key scientific studies with the remarkably complacent but incorrect claim: "On the issue of scientific conduct and procedure, we simply note that the peer review process is fundamental to all academic endeavours and is no different for climate science than for any other branch of science". Certainly no new pharmaceutical product would now reach the UK market with the disclosure standards of the "hockey stick" or HadCRUT3[36] or based upon current climate models. In the IPCC (2007) WGI Chapter 3, of which Dr Phil Jones is a coordinating lead author, his 1990 paper[37] is cited to support the argument that urbanisation effects are fully removed from the surface temperature record. Under a Freedom of Information request (CRU Ref, FOI_07–09) some previously unpublished data used in this paper have now been released, but in answer to a question on the undisclosed methodology, CRU supplied the following answer:

> We do not have any information about why the sites for the 1990 paper were selected as Dr. Jones is unaware of how his collaborators selected the sites.

[36] HadCRUT3 is used by IPCC (2007) as the globally averaged temperature series but its data and methodology are not available to critics. A Freedom of Information request is currently (4th June 2007) being disputed by the Climatic Research Unit under their reference (FOI_07–04). See http://www.climateaudit.org/?p=1471#comments for details.

[37] Jones, P. D., *et al.* (1990), 'Assessment of Urbanization Effects in Time Series of Surface Air Temperature Over Land', *Nature*, **347**: 169–172.

We reported the additional fact in C2006 that it required direct demands from the US House of Representatives to force disclosure (still far from complete) of the flawed "hockey stick" methodology of Michael Mann and co-authors. We now report here that several requests are being made under British Freedom of Information legislation for data and methodology on other studies that the IPCC rely upon. The fact is that the current disclosure standards in climate research are entirely inadeqate for so important a field. One example of an appropriate policy for data disclosure that the IPCC might adopt forthwith is to be found at the *Journal of Political Economy*,[38] which says [emphasis added]:

> It is the policy of the Journal of Political Economy to publish papers only if the data used in the analysis are clearly and precisely documented and are readily available to any researcher *for purposes of replication. Authors of accepted papers that contain empirical work, simulations, or experimental work must provide to the Journal, prior to publication, the data, programs, and other details of the computations sufficient to permit replication.* These will be posted on the JPE Web site. The Editor should be notified at the time of submission if the data used in a paper are proprietary or if, for some other reason, the requirements above cannot be met.

M2007 suggest on p. 222 that, because they are "dealing with the assessment of risk", they are justified in insisting that their critics should prove them wrong rather than they prove themselves right. This is an appalling suggestion and, if widely applied, is a recipe for misconceived policies on any number of fronts. But even were they able to justify this exceptionally, because of the scale of the risk they fear, they can not at the same time justify the chronic lack of full disclosure in some studies, which would require so little expenditure to remedy that it might only cost the equivalent of the Emissions Trading System brokers' commissions of a day. As such, the 'insurance policy' of spending a small amount to ensure adequate standards in the science is far better value than taking the expensive actions proposed in the Stern Review that are based upon such uncertain science. Good science does not take sides, nor does it fear criticism; rather, criticism is always best used to improve the science.

[38] http://www.journals.uchicago.edu/JPE/datapolicy.html

Other criticisms

We comment now, more briefly, on some of the other science criticisms of our original commentary.

A2007 (p. 230) complain that we ignore the full discussion of the CO_2 fertilization effect that occurs in Chapter 3 of the IPCC report, and base our comments only on a brief reference in the Executive Summary. This criticism, in fact, not only highlights the cherrypicking associated with the Stern Review's Executive Summary and its "headline" conclusions but also the fatal weakness in the way that most IPCC advice is routed, which is the disconnect that exists between the real science (much of which is well discussed in the detailed chapters of the reports of IPCC Working Group III) and the introductory Summary for Policymakers, which is all that is consulted by most policy makers.

We are quite puzzled by some of the statements in A2007. First, they claim that the "impacts of climate change would, therefore, be the same under each of the A1 variants" (A2007, p. 230). This is unlikely since the amount of climate change would be different under each variant. In fact, this is only possible if under each variant, with respect to impacts, the increase in adaptive capacity *exactly* cancels out the effects of temperature change, which is most unlikely especially considering that GDP per capita, a major determinant of adaptive capacity, is similar under each A1 variant.

Second, A2007 claim that we erred in asserting that agricultural productivity and hunger results were based on "only limited adaptation" (p. 230). But Parry *et al.* (2004),[39] the Stern Review's original source of most of these results, note specifically on p. 57 that in their study, farm level adaptation is based on the "*current range of agricultural technologies* available around the world, but by the 2080s agricultural technology is likely to be very different and the models may underestimate the farm production achievable" (emphasis added). They further note that their model "does include future trends in yield improvement, but not technological developments induced by negative climate change impacts, such as the development of bioengineered varieties." Moreover, A2007 note that productivity is

[39] Parry, M. L., C. Rosenzweig, I. Iglesias, M. Livermore, and G. Fischer (2004), 'Effects of Climate Change on Global Food Production Under SRES Emissions and Socio–Economic Scenarios', *Global Environmental Change*, **14** (1): 53–67.

assumed to grow at the "1990s rate of 1% per year" (p. 230), although it is not clear whether that is a linear or compounded rate. But, in fact, growth in cereal yields—Parry *et al.* use cereal production as a surrogate for agricultural production—increased by 1.4% per year (linear) or 1.3% per year (compounded) between 1989/1991 and 2002/2004.[40] Over the 95-year period (from 1990–2085) covered by the analysis the difference between a 1% and 1.3% (compounded) or 1.4% (linear) growth rate per year could underestimate the total agricultural production by anywhere between 16% and 23%. This difference is substantially larger than the estimated declines in production due to climate change alone. For instance, assuming *zero* fertilization effect, climate change would reduce production by, at most, 9% in 2085 under the A2 scenario, the scenario which gives the highest increase in the population at risk of hunger.[41] Assuming full fertilization, this decrease, estimated at 0.9%, would be much more modest. These results also indicate that future global agricultural production and hunger are far more sensitive to technological change and other factors than to climate change.

A2007 also note that "low cost local additional irrigation" is assumed to be applied 100% in developed countries and 75% in developing countries, while major national schemes are applied in developed countries only (p. 230). Considering that by 2085 the average GDP per capita of today's developing countries will exceed the average GDP per capita that existed in the developed countries in 1990 for all scenarios except A2, these assumptions may underestimate future adaptive capacity and, therefore, overestimate negative impacts of climate change while simultaneously underestimating positive impacts.

Regarding ecosystem impacts, we note that A2007 chose not to address substantive issues that C2006 raised (pp. 182–183) about the broad methodology used in the analyses in Thomas *et al.* (2004). As noted in C2006, most of the studies used for ecosystem impacts employ climate suitability studies but a basic issue is whether such studies are able to predict extinction risks under different climatic regimes because atmospheric concentrations of CO_2, rates of plant growth, water use efficiency, the energy requirements of species and their predator–prey relationships

[40] Food and Agricultural Organisation, *FAOSTAT*, available at http://faostat.fao.org/site/408/default.aspx (Visited 19 April 2007.)
[41] This is estimated from information provided in Fig. 12 and the last paragraph on p. 67 of Parry *et al.* (2004), *loc. cit.*

would all be different from what they are today.[42] No less important, existing threats to ecosystems and species would also be different under future climatic conditions. For instance, higher CO_2 and increases in agricultural productivity may reduce the demand for cropland, thereby reducing habitat loss,[43] which is probably the single most important threat to terrestrial biodiversity.[44] Similarly, higher water use efficiency in the agricultural sector might reduce water diverted for agriculture which is the largest threat to freshwater biodiversity.[45] As far as we can tell, none of these critical factors is considered in the studies used by the Stern Review.

Finally, we are gratified to have A2007 confirm that, with respect to water resources and vector-borne diseases, the Stern Review's numbers do not reflect "actual impacts" (p. 231). If anything, they reflect different measures of "potential exposure" which, moreover, seem to be driven more by population growth than climate change itself.

We agree with the general view of Glikson (2007) regarding the importance of geological context for understanding modern climate change. Regarding the specific points that he raises, however, we note that his comparisons between modern and geological rates are often selectively chosen.

For example, regarding rates of temperature change, there is little difference between the rates of warming measured instrumentally in the early and later parts of the 20th century, yet it is generally acknowledged that the early 20th century change was driven by natural factors. Remembering the difficulty that we have no true measures of global, as opposed to local, change prior to instrumental measurement, we note again that the typical rates of temperature rise and fall during the Holocene in the Greenland ice core are between + and –2.5°C/century, whereas, depending upon the dataset used, the alleged "abnormal" rate of late 20th century change is between 1 and 2°C/century.

Regarding sea-level change, and like the IPCC, Glikson makes little attempt to disentangle the complex issue of eustatic versus local relative sea-level, which is highly variable worldwide and which is what counts for

[42] We should also note that, in general, these analyses do not consider persistence of species or their ability to adapt, among other things.
[43] See, e.g., Levy, P. E., M. G. R. Cannell, and A. D. Friend (2004), 'Modelling the Impact of Future Changes in Climate, CO_2 Concentration and Land Use On Natural Ecosystems and the Terrestrial Carbon Sink', *Global Environmental Change*, **14** (1): 21–30.
[44] See, e.g., Goklany, I. M. (1998), 'Saving Habitat and Conserving Biodiversity on a Crowded Planet', *BioScience*, **48**: 941–953.
[45] *Ibid.*

future planning purposes. The rates of eustatic sea level change that he cites are entirely unexceptional, and, translated into local context, will generally result in a continuation of historic natural trends.

Finally, regarding total solar irradiance, it is indeed estimated that since 1980 changes in TSI are inadequate on their own to account for the global temperature increase observed, and that therefore other causes have to be examined. But, again like the IPCC, Glikson simply presumes that human-sourced CO_2 must be the culprit rather than examining the possibility of intrinsic variation or of factors such as solar magnetism and the modulating effect that it exercises on earthbound cosmic radiation with its concomitant effect on cloud nucleation.

Summary and conclusion

Leaving aside the cut and thrust of specific arguments about the danger of human-caused climate change, some only of which we have covered in the body of this reply, it is useful here to recap briefly what we believe to be a prudent and sensible assessment of the real climate change issue.

Climate changes naturally all the time. Human activities have an effect on the local climate, for example in the vicinity of cities (warming) or near large areas of changed land usage (warming or cooling, depending upon the changed albedo). Logically, therefore, humans must have an effect on global climate also. This notwithstanding, a distinct human signal has not yet been identified within the variations of the natural climate system, to the degree that we cannot even be certain whether the global human signal is one of warming or cooling. Though it is true that many scientists anticipate that human warming is the more likely, no strong evidence exists that any such warming would be dangerous.

The gentle global warming that probably occurred in the late 20th century falls within previous natural rates and magnitudes of warming and cooling, and is prima facie quite unalarming, especially when consideration is given to the likelihood that the historic ground temperature records used to delineate the warming are warm-biased by the urban heat island and other effects. Once corrected for non-greenhouse climate agents such as El Niños and volcanic eruptions, the radiosonde (since 1958) and satellite (since 1979) records show little if any recent warming and certainly none of untoward magnitude.

Atmospheric carbon dioxide is indeed a greenhouse gas, but the empirical evidence shows that the warming effect of its increase at the rates of modern industrial emission and accumulation is minor, given an assumed pre-industrial level of about 280 ppm and noting the established logarithmic relationship between gas concentration increases and warming. As one such empirical test, it can be noted too that no global increase in temperature has now occurred since 1998 despite an increase in carbon dioxide concentration over the same 8 years of about 15 ppm (4%).

Putative human influence aside, it is certain that natural climate change will continue, sometimes driven by unforced internal variations in the climate system and at other times forced by factors that we do not yet understand. The appropriate public policy response is, first, to monitor climate accurately in an ongoing way; and, second, to respond and adapt to any changes—both warmings and the likely more damaging coolings—in the same way that we cope with other natural events such as droughts, cyclones, earthquakes and volcanic eruptions.

Neither the Stern Review itself, nor the additional papers that our critique has stimulated, address the above cautious and widely held assessment of the situation. Instead, straw-man arguments are erected and attacked, detail is endlessly obfuscated and IPCC orthodoxy is relentlessly repeated.

In dealing with the certainties and uncertainties of climate change, the key issue is prudence. The main certainty is that natural climate change will continue, and that some of its likely manifestations—sea-level rise and coastal change in particular locations, for example—will be expensive to adapt to. But adapt we must and will. Moreover, reducing vulnerability to today's climate-sensitive problems will also help the world cope with future challenges from climate change whether that is due to natural variability, anthropogenic greenhouse gas emissions or other human causes.[46] The most prudent way of ensuring that happens is to build wealth into the world economy and to be receptive to new technologies. This will not be achieved by irrational restructuring of the world's energy economy in pursuit of the chimera of "stopping" an alleged dangerous human-caused climate change that, in reality, can neither be demonstrated nor measured at this time.

[46] Goklany, I. M. (2005), 'A Climate Policy for the Short and Medium Term: Stabilization or Adaptation?', *Energy & Environment*, **16**: 667–680.

Nicholas Stern, Chris Taylor. See allHide authors and affiliations. Science 13 Jul 2007: Vol. 317, Issue 5835, pp. 203-204 DOI: 10.1126/science.1142920. Nicholas Stern. Find this author on Google Scholar. Find this author on PubMed.Â Thank you for your interest in spreading the word about Science. NOTE: We only request your email address so that the person you are recommending the page to knows that you wanted them to see it, and that it is not junk mail. We do not capture any email address. Your Email. The Stern Review on the Economics of Climate Change is a 700-page report released for the Government of the United Kingdom on 30 October 2006 by economist Nicholas Stern, chair of the Grantham Research Institute on Climate Change and the Environment at the London School of Economics (LSE) and also chair of the Centre for Climate Change Economics and Policy (CCCEP) at Leeds University and LSE. The report discusses the effect of global warming on the world economy. Although not the first economic report The Stern Review highlights several impacts of climate change. One is water. The work. here is based on Arnell (2004). The Stern Review correctly that Arnell (2004) does â€œnot. include adaptationâ€ and is therefore severely biased. Food is another highlighted impact.Â insurance, the Stern Review consistently selects the most pessimistic study in the. literature. For refugees, the Myers and Kent (1995) are the highest, and the Stern Review. duly highlights that â€œsome estimates suggest that 150-200 million people may become. permanently displacedâ€. This multitude of interactions is what makes climate science and climate predictions so very complex and so very sensitive. What is causing climate change? It is now beyond any reasonable doubt that climate change is happening, itâ€™s happening fast, and it is caused by the human input of GHGs into the atmosphere.Â As was firmly established in the 2001 IPPC report, and is supported by Sternâ€™s recent review, this increase in atmospheric GHG concentration is the result of human activity. Crucially, Stern notes that while natural factors (such as orbital variation and solar activity) could have explained some of the early-19th-century trends, we would then have expected a slight cooling over the past 50 years if they were due to natural factors alone, and this strongly contrasts with the observed rise. Since the Stern Reviewâ€™s publication, other economists have made estimates of what it would cost to address climate change, but the Stern Review still stands out as a seminal document similar to the Intergovernmental Panel on Climate Change reports on science. With the 10-year anniversary coming up at the end of October, Climate Central reached out to a group of leading and up-and-coming climate economists dealing with the challenge of valuing climate action now and into the future. Their answers are below, lightly edited for clarity and brevity. Whatâ€™s the legacy of the Stern Review? How have