Grantham Research Institute on
Climate Change and
the Environment

Comment: 'Knock knock: where is the evidence for dangerous human-caused global warming?' by Robert M. Carter

Robert E. T. Ward

September 2010

Grantham Research Institute on Climate Change and the Environment

Working Paper No. 28

THE GRANTHAM FOUNDATION
FOR THE PROTECTION OF THE ENVIRONMENT

LSE THE LONDON SCHOOL OF ECONOMICS AND POLITICAL SCIENCE

The Grantham Research Institute on Climate Change and the Environment was established by the London School of Economics and Political Science in 2008 to bring together international expertise on economics, finance, geography, the environment, international development and political economy to create a world-leading centre for policy-relevant research and training in climate change and the environment. The Institute is funded by the Grantham Foundation for the Protection of the Environment, and has five research programmes:

1. Use of climate science in decision-making
2. Mitigation of climate change (including the roles of carbon markets and low-carbon technologies)
3. Impacts of, and adaptation to, climate change, and its effects on development
4. Governance of climate change
5. Management of forests and ecosystems

More information about the Grantham Research Institute on Climate Change and the Environment can be found at: http://www.lse.ac.uk/grantham.

Comment: 'Knock, Knock: Where is the Evidence for Dangerous Human-Caused Global Warming?' by Robert M. Carter

Robert Edward Thomas Ward
Grantham Research Institute on Climate Change and the Environment
London School of Economics and Political Science
Houghton Street
London
WC2A 2AE
UK
(email: r.e.ward@lse.ac.uk)

Introduction

Carter (2008) notes that for climate change "sound science [sic] understanding is an essential prerequisite to any meaningful economic analysis". Unfortunately his paper contains serious and systematic errors about the causes and potential consequences of climate change, the overall effect of which is to convey an inaccurate and misleading impression of the scientific evidence. Indeed, the overall tone of Carter (2008) is one of a polemic rather than an objective analysis of the facts. An itemisation of all the inaccuracies in Carter (2008) would require a great deal of space, so this paper identifies and corrects some of the most important errors.

The work of the Intergovernmental Panel on Climate Change (IPCC)

Carter (2008) wrongly alleges that "the science advice of the IPCC is politically cast, and thereby fundamentally flawed to a degree that makes it unsuitable for use in detailed economic forecasting and policy creation". He makes several inaccurate assertions about the work of the IPCC, including that its focus "has been on comparing contemporary climate change with that of the last 150 years of instrumented temperature records, sometimes extending back to around 1,000 years using proxy measurements such as tree ring analysis".

Carter (2008) claims that the IPCC is "constituted under the United Nation's [sic] Framework Convention on Climate Change". In fact, the IPCC was established by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) in 1988, four years before the United Nations Framework Convention on Climate Change (UNFCCC) was adopted in 1992. Its role, according to the 'Principles Governing IPCC Work' (Intergovernmental Panel on Climate Change 2006), is to "assess on a comprehensive, objective, open and transparent basis the scientific, technical and socio-economic information relevant to understanding the scientific basis of risk of human-induced climate change, its potential impacts and options for adaptation and mitigation". Carter (2008) describes this as an "unbalanced brief" which "inevitably leads to unbalanced advice".

Carter (2008) characterises the IPCC as "not a scientific but a political body, albeit advised by scientists". This is misleading. The IPCC has produced a number of reports, including four major assessments, in 1990, 1995, 2001 and 2007. The Fourth Assessment Report consisted of three volumes, on 'The Physical Science Basis' (Intergovernmental Panel on Climate Change 2007a), 'Impacts, Adaptation and Vulnerability' (Intergovernmental Panel on

Climate Change 2007b), and 'Mitigation of Climate Change' (Intergovernmental Panel on Climate Change 2007c). While these volumes were subject to review by participating governments, and each included a 'Summary for Policymakers' which was agreed by government representatives meeting in plenary sessions, they were written by working groups composed of researchers employed in universities and institutions around the world. The Fifth Assessment Report is due to be published between 2013 and 2014.

Carter (2008) alleges that the reports of the IPCC have "talked up the threat of dangerous human-caused change", and describes them as "fundamentally flawed". However, the Principles state: "IPCC reports should be neutral with respect to policy, although they may need to deal objectively with scientific, technical and socio-economic factors relevant to the application of particular policies". The main conclusions of the assessment reports have been endorsed by major scientific bodies around the world, including joint statements by the national science academies of Brazil, Canada, China, France, Germany, India, Italy, Japan, Mexico, Russia, South Africa, United Kingdom and United States of America (Academia Brasiliera de Ciéncias *et al*. 2007, 2008, 2009). Analysis has demonstrated that the main conclusions of the IPCC reports are consistent with the vast majority of scientific papers published in journals over the last 15 years (Oreskes 2004; Anderegg *et al*. 2010).

Nevertheless, Carter (2008) correctly observes that the IPCC and its reports have been subject to criticism. While much of this criticism has emanated from individuals and organisations who oppose the IPCC on ideological or political grounds (McCright and Dunlap 2003; 2010), some scientists who have been involved in the preparation of the assessment reports have also called for improvements (e.g. Hulme *et al.* 2010). In addition, the IPCC admitted in 2010 that some minor errors had occurred in the second volume of its Fourth Assessment Report. These included the statement: "Glaciers in the Himalaya are receding faster than in any other part of the world and, if the present rate continues, the likelihood of them disappearing by the year 2035 and perhaps sooner is very high if the Earth keeps warming at the current rate". The IPCC acknowledged that these were "poorly substantiated estimates of rate of recession and date for the disappearance of Himalayan glaciers" and had occurred because "the clear and well-established standards of evidence, required by the IPCC procedures, were not applied properly" (Intergovernmental Panel on Climate Change 2010).

Notwithstanding the errors, the Netherlands Environmental Assessment Agency (PBL 2010) concluded from an analysis of statements on projected regional impacts contained in the second volume that "the summary conclusions are considered well founded and none were found to contain any significant errors".

However, as a result of controversy and media coverage surrounding this and other errors in the second volume of the Fourth Assessment Report, the United Nations asked the InterAcademy Council (consisting of representatives from the world's leading national science academies) to carry out a review of the processes and procedures of the IPCC (InterAcademy Council 2010).

Apart from mischaracterising the work of the IPCC, Carter (2008) also misrepresents the views of John Houghton, who chaired its working group on the science of climate change for the assessment reports in 1990, 1995 and 2001. Carter (2008) states:

> "The IPCC is the United Nations body whose second chairman, John Houghton, wrote in 1994 that 'unless we announce disasters, no one will listen'. From that point forward, it

> was obvious that IPCC pronouncements needed to be subjected to independent critical analysis; in fact, the opposite has happened, and increasingly the world's press and politicians have come to treat IPCC utterances as if they were scribed in stone by Moses."

However, the quote attributed to Houghton is entirely fictional. In a letter published by the UK newspaper 'The Observer' in February 2010, Houghton stated: "That quote from me is without foundation. I have never said it or written it." It seems that the fabricated quote first appeared in a column by Piers Akerman (2006) in the Australian newspaper 'The Sunday Telegraph' (Connor 2010), which wrongly claimed that it had been published in Houghton (1994). This false statement has subsequently been repeated numerous times by opponents of the IPCC (e.g. Monckton 2006).

Not only is the quote fictional, but it conveys a completely different impression from statements appearing in the 'Preface' in Houghton (1994), such as "scientists have a responsibility to communicate the best possible information about the likely magnitude of climate change, along with clear statements of the assumptions made and the level of uncertainty in the estimates". Houghton (1994) also states:

> "The key intergovernmental body which has been set up to assess the problem of global warming is the Intergovernmental Panel on Climate Change (IPCC), formed in 1988. At its first meeting in November of that year in Geneva, the Panel's first action was to ask for a scientific report so that, so far as they were known, the scientific facts about global warming could be established. It was imperative that politicians were given a solid scientific base from which to develop the requirements for action."

Carter (2008) makes other inaccurate and unsubstantiated allegations, too numerous to individually rebut in this note, about the work of the IPCC. It is then perhaps not surprising that he should, in contrast to national science academies and scientific organisations around the world, disregard the main conclusions of the first volume of the Fourth Assessment Report (Intergovernmental Panel on Climate Change, 2007a), some of which are outlined in the following sections.

Increase in global average temperature

Carter (2008) asserts that "the late 20th century phase of rising temperature terminated in 1998", and that "no warming has occurred since 1998". These statements give a misleading impression of the available scientific evidence.

Three records of global average temperature from surface station measurements are independently compiled by the UK Met Office (in collaboration with the Climatic Research Unit at the University of East Anglia), the NASA Goddard Institute of Space Studies (GISS) and the National Climatic Data Center (NCDC) of the US National Oceanic and Atmospheric Administration. Each of these records show that 9 of the 10 warmest years since records began have occurred since 2000, and the World Meteorological Organization (2010) stated that "the period 2000-2009 was the warmest decade on record since the beginning of modern instrumental measurements around 1850".

In the UK Met Office record, which begins in 1850, the two warmest years were 1998 and 2005 respectively, while the NCDC record, which begins in 1880, ranks 2005 as the warmest with 1998 second warmest, and GISS (which also begins in 1880) ranks 2005 as the warmest

with 2009 in second place and 1998 in third place. Despite these differences, Figure 1 demonstrates that the three records show the same pattern of warming over the last century. Overall, the global average temperature has increased by about 0.8°C over the last century, and the first decade of the 21st century (2000-2009) was 0.77°C warmer than the first decade of the 20th century (1900-1909) (National Research Council 2010). According to the NCDC (2010), the period between January and July 2010 was the warmest first seven months of any year since records began in 1880.

However, as can be seen clearly in Figure 1, while the overall warming trend is obvious over the length of the entire record, it also shows short periods of cooling and warming. Liebmann *et al.* (2010) carried out statistical analyses of these trends within the UK Met Office HadCRUT3 record, noting that "changes shorter than a few decades can be either positive or negative", and pointing out that a "recent cooling trend is evident in the global record beginning in 2001" with a change of -0.07°C. But Liebmann *et al*. (2010) concluded: "Such changes, however, are not statistically significant and are in fact relatively common in the historical record".

Carter (2008) also claims that "the historic ground temperature records that are usually cited in support of the warming are warm-biased by the urban heat island effect". In fact, all of the three records of global average temperature take into account the fact that weather stations in some areas may have been affected by increased urbanisation, which could have biased measurements. Brohan *et al.* (2006) described the steps taken to remove the impact of increased urbanisation on the HadCRUT3 record, while Smith *et al.* (2008) and Hansen *et al.* (2010) described the steps taken by NCDC and GISS, respectively.

Parker (2010) reviewed the available evidence about the influence of urbanisation and concluded that the impact was much smaller than the overall warming trend that has been observed in the last 100 years. He stated: "The impact is small because assiduous efforts have been made by the compilers of global surface air temperature records to avoid or compensate for urban warming". Indeed, it is clear from Figure 2 that the warming recorded by measurements of global land surface temperature is much the same as that shown by measurements of global sea surface temperature which, of course, could not be influenced by increased urbanisation.

Carter (2008) makes the further erroneous assertion that the measurements of the temperature of the troposphere, the lowest layer of the atmosphere, by radiosonde sensors mounted on weather balloons show "no significant warming between 1958 and 2005". As Figure 3 illustrates, this is untrue. According to the National Research Council (2010), "radiosonde and satellite-derived data both show that the troposphere...has warmed substantially over the past several decades".

The IPCC (2007a) pointed out that the direct measurement of warming is consistent with the observed melting of land and sea ice across the world and a rise in global average sea level. For this reason, the IPCC (2007a) concluded: "Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level".

Relative scale of recent global warming compared with the past

Carter (2008) states:

"The gentle, short-term global warming that occurred in the last 20th century falls within previous natural rates and magnitudes of warming and cooling. It is therefore *prima facie* unalarming..."

He also claims: "A variety of detailed proxies from around the world can be used to construct a global temperature estimate for the last 1,500 years that confirms the greater warmth of the Mediaeval over the Late 20th Century Warm Period", and references a figure from Loehle and McCulloch (2008).

Constructions of global average temperature prior to the start of the instrumental record in the 19th century are based on the analysis of proxies, such as tree rings, isotopic compositions of sedimentary rocks, and borehole temperatures. As with weather stations, proxies provide information about local climate, and there are many challenges in using these to construct an overall picture of the global climate.

Carter (2008) fails to point out that the reconstruction offered by Loehle and McCulloch (2008) ignores all data from tree ring studies and only extends to 1935, hence excluding the warming of the late 20th century.

In contrast to the selective and inaccurate account by Carter (2008) of the available palaeoclimate evidence, the IPCC (2007a) reviewed all of the published reconstructions and acknowledged the limitations and uncertainties of proxy measurements, particularly the shortage of data about the Southern Hemisphere. It concluded: "Average Northern Hemisphere temperatures during the second half of the 20th century were *very likely* [>90% probability] higher than during any other 50-year period in the last 500 years and *likely* [>66% probability] the highest in at least the past 1,500 years."

However, it is clear from the available evidence that the Earth was warmer than today at some point in its recent geological past. However, this does not mean that the warming of the last century must be "natural": it would be equivalent to arguing that humans cannot be responsible for the demise of any species because previous mass extinctions in the Earth's history prove that they are a natural occurrence. As the National Research Council (2006) emphasised: "Surface temperature reconstructions for periods prior to the industrial era are only one of multiple lines of evidence supporting the conclusion that climatic warming is occurring in response to human activities, and they are not the primary evidence". The likely causes of the recent warming are considered in the next section.

Greenhouse gases and the greenhouse effect

Carter (2008) states that "even educated persons mostly have no comprehension that the overwhelmingly dominant greenhouse gas is water vapour; that, as a minor greenhouse gas, carbon dioxide causes less than 4% of the warming produced by all atmospheric greenhouse gases; and that human emissions represent just a tiny portion (~3%) of that 4%". These figures are completely inaccurate. Carter (2008) cites as a source for these figures a page (Hieb 2003) posted on a website about 'Plant Fossils of West Virginia'.

One of the many erroneous assertions made by Hieb (2003) was that the atmospheric concentration of carbon dioxide is 368.4 parts per million (ppm) of which the anthropogenic contribution is 11.88 ppm. In fact, the current atmospheric concentration of carbon dioxide is

387 ppm (Tans 2010), having increased steadily from a pre-industrial level between 1000 and 1750 AD of 275 to 285 ppm (Intergovernmental Panel on Climate Change 2007a). When other compounds such as methane are also taken into account, the atmospheric concentration of greenhouse gases is estimated to be about 435 ppm of carbon-dioxide-equivalent, and increasing at a rate of about 1.5 ppm each year (Bowen and Ranger 2009).

There is little dispute within the scientific literature that human activities have been the main cause of the increase of more than 100 ppm in the concentration of carbon dioxide since industrialisation (i.e. almost ten times the rise claimed by Hieb (2003)). The IPCC (2007a) concluded: "The primary source of the increased atmospheric concentration of carbon dioxide since the pre-industrial period results from fossil fuel use, with land-use change providing another significant but smaller contribution". But Carter (2008) acknowledged only that "human emissions are one of the main causes". Others have claimed that the rise may be due to natural sources. Plimer (2009), for instance, suggested that volcanoes produce more carbon dioxide than human activities. However, the available evidence indicates that volcanoes emit an estimated 132 to 378 million tonnes each year, whereas human activities in 2008 produced 36,300 million tonnes (Gerlach 2010).

There is not much dispute either in the scientific literature that greenhouse gases in the atmosphere warm the surface of the Earth, as this has been well-established since the 19th century. In 1824, Fourier wrote (Burgess 1827):

"All the terrestrial effects of solar heat are modified by the interposition of the atmosphere and the presence of water. The great motions of these fluids render the distribution more uniform. The transparency of the waters appears to concur with that of the air in augmenting the degree of heat already acquired, because luminous heat flowing in, penetrates, with little difficulty, the interior of the mass, and non-luminous heat has more difficulty in finding its way out in a contrary direction."

Tyndall (1861) described the results of laboratory experiments to identify water vapour, carbon dioxide and other gases as responsible for creating the greenhouse effect of the atmosphere. It is now well understood that greenhouse gases, which trap some of the infra-red long wave radiation that is emitted after solar radiation is absorbed by the Earth, causes the planet's surface to be about 33°C warmer than it otherwise would be (Taylor 2005). Of this greenhouse effect, about 60% can be attributed to water vapour (which constitutes between 0 and 4% of the air by volume, with a typical value of 0.8%; Taylor 2005), with about 26% due to carbon dioxide (which constitutes about 0.0387% of the air by volume), based on calculations of the Earth's annual global mean energy budget (Kiehl and Trenberth 1997). The gases overlap in their contributions to the greenhouse effect, and this calculation does not take into account clouds and aerosols which also contribute.

The increase in the atmospheric concentrations of carbon dioxide and other gases since industrialisation has enhanced the greenhouse effect, in line with predictions first made in the 19th century. Arrhenius (1896) published rudimentary estimates of how changes in the atmospheric concentration of carbon dioxide would effect the Earth's climate at different latitudes. He concluded: "A simple calculation shows that the temperature in the arctic regions would rise about 8° to 9°C, if the carbonic acid increased to 2.5 or 3 times its present value". As the atmospheric concentration of carbon dioxide has risen by almost 40% due to human activities, its enhancement of the greenhouse effect has been much greater than the 0.12% increase indicated by Carter (2008), although it is difficult to estimate precisely (for

instance, the warming of the atmosphere has led to an increase in the average humidity and water vapour content, a feedback which has further enhanced the greenhouse effect).

A better way of estimating the likely impact of greenhouse gases is through the climate sensitivity, defined as the temperature change at equilibrium due to a doubling of the concentration of carbon dioxide (i.e an increase from the pre-industrial level of about 280 ppm to 560 ppm; IPCC 2007a). Equilibrium climate sensitivity takes into account both feedbacks and the lag in the response of the climate system (particularly the oceans) to changes in atmospheric concentrations of greenhouse gases.

Carter (2008) claims "IPCC models, which invoke a positive feedback loop from water vapour, predict much greater increases up to 6.4°C for a doubling in carbon dioxide." He also states that "alternative calculations" suggest "an increase of only 0.2-1.0°C for a doubling of carbon dioxide", citing Isdo (2001) which is neither listed in his 'References' nor exists on any database of scientific publications. In fact, the IPCC (2007a) concluded:

"Analysis of models together with constraints from observations suggest that the equilibrium climate sensitivity is *likely* [i.e. >66% probability] to be in the range 2°C to 4.5°C, with a best estimate value of 3°C. It is very unlikely [i.e., <10% probability] to be less than 1.5°C."

The correlation between the rise in global average temperature and the increase in atmospheric concentrations of greenhouse gases during the 20th century is what would be expected from the observations and theory that have been developed since the early 19th century. However, there are other lines of evidence for attributing the rise in global average temperature and associated changes in the climate over the past 50 years to the rise in atmospheric concentrations of greenhouse gases due to human activities.

Attribution of recent climate change to human activities

Carter (2008) states that "no summed human effect on global temperature has ever been identified or measured", and that "we cannot even be certain whether the net human signal is one of warming or cooling". This is inaccurate and misleading. Apart from the obvious increase in global average temperature since atmospheric concentrations of greenhouse gases began to rise after industrialisation, there are many lines of evidence for attributing recent warming and climate change to human activities. IPCC (2007a) devotes a whole chapter to "Understanding and attributing climate change" (Hegerl *et al.* 2007).

Carter (2008) claims "It remains the case, amazingly, that IPCC's claims of a dangerous human influence on climate now rest almost solely on their unrealistic, unvalidated GCM [General Circulation Model] climate projections". This is entirely false. IPCC (2007a) pointed out: "An anthropogenic signal has now more clearly emerged in formal attribution studies of aspects of the climate system beyond global-scale atmospheric temperature, including changes in global ocean heat content, continental-scale temperature trends, temperature extremes, circulation and arctic sea ice extent".

Analyses by the National Research Council (2010) and Stott *et al.* (2010) have confirmed and updated the findings of Hegerl *et al.* (2007). The National Research Council (2010) summarised the evidence as follows:

- both the basic physics of the greenhouse effect and more detailed calculations using sophisticated models of atmospheric radiative transfer indicate that increases in

atmospheric greenhouse gases should lead to warming of the Earth's surface and lower atmosphere;

- the Earth's surface temperature has unequivocally risen over the past 100 years, to levels not seen in at least several hundred years and possibly much longer, at the same time that human activities have resulted in sharp increases in carbon dioxide and other greenhouse gases;
- detailed observations of temperatures, greenhouse gas increases, and other climate forcing factors from an array of instruments, including Earth-orbiting satellites, reveal an unambiguous correspondence between human-induced increases in greenhouse gases and planetary warming over at least the past three decades, in addition to substantial year-to-year natural climate variability;
- the vertical pattern of atmospheric temperature change over the past few decades, with warming in the lower atmosphere and cooling in the stratosphere (as shown in Figure 3), is consistent with the pattern expected due to greenhouse gas increases and inconsistent with the pattern expected if other climate forcing agents (eg changes in solar activity) were responsible;
- estimates of changes in temperature and forcing factors over the first seven decades of the 20th century are slightly more uncertain and also reveal significant decadal-scale variability, but nonetheless indicate a consistent relationship between long-term temperature trends and estimated forcing by human activities;
- the horizontal pattern of observed surface temperature change over the past century, with stronger warming over land areas and at higher latitudes, is consistent with the pattern of change expected from a persistent positive climate forcing;
- detailed numerical model simulations of the climate system are able to reproduce the observed spatial and temporal pattern of warming when anthropogenic greenhouse gas emissions and aerosols are included in the simulation, but not when only natural climate forcing factors are included;
- both climate model simulations and reconstructions of temperature variations over the past several centuries indicate that the current warming trend cannot be attributed to natural variability in the climate system;
- estimates of climate forcing and temperature changes on a range of timescales, from the several years following volcanic eruptions to the 100,000+ year Ice Age cycles, yield estimates of climate sensitivity that are consistent with the observed magnitudes of observed climate change and estimated climate forcing; and
- there is not any compelling evidence for other possible explanations of the observed warming, such as changes in solar activity, changes in cosmic ray flux, natural climate variability, or release of heat stored in the deep ocean or other climate system components.

In his 'Discussion' section, Carter (2008) attempts to attribute recent trends in global average temperature to solar activity:

"Ironically, though the late 20th century warming was manifestly not dangerous, the current cooling may yet prove to be because of mounting evidence of solar causation. A relationship exists between the length of the sunspot cycle and the annual average temperature."

He cites a paper by Christensen and Lassen (1991) in support of the latter statement. However, Damon and Laut (2004) have shown that the apparent agreement between a reduction in sunspot cycle lengths and an increase in global average temperature between 1880 and 1990 relied heavily on misleading presentation of data for the period from 1960.

When the correct data were added, it was clear that the sunspot cycle lengths have remained roughly constant after 1960 while temperature has increased markedly. Damon and Laut (2004) concluded:

"Now the sensational agreement with the recent global warming, which drew worldwide attention, has totally disappeared. Nevertheless, the authors and other researchers keep presenting the old misleading graph."

The IPCC (2007a) concluded: "Most of the observed increase in global average temperatures since the mid-20th century is *very likely* [ie >90% probability] due to the observed increase in anthropogenic greenhouse gas concentrations". The National Research Council (2010) concluded: "Many lines of evidence support the conclusion that most of the observed warming over at least the last several decades is due to human activities". Stott et al. (2010) concluded that "there is an increasingly remote possibility that climate change is dominated by natural rather than anthropogenic factors". These statements, each based on clear and compelling evidence, are in stark contrast to the following inaccurate statement by Carter (2008): "Little that is predicted by the dangerous, human caused global warming hypothesis has yet been observed in empirical data".

Expected and potential future changes in climate

The IPCC (2007a) pointed out that the Earth was already "committed" to a further rise in global average temperature even if atmospheric concentrations of greenhouse gases had been held steady at their 2000 levels (with carbon dioxide at about 369 ppm). It stated: "Model experiments show that even if all radiative forcing agents were held constant at year 2000 levels, a further warming trend would occur in the next two decades at a rate of about 0.1°C per decade, due mainly to the slow response of the oceans".

Beyond the next two decades, estimates of potential future changes in global average temperature, and associated changes in the climate, depend on a number of factors, including, of course, atmospheric concentrations of greenhouse gases. The IPCC (2007a) provided projections of future temperature development up to 2100 based on the outputs of general circulation models for a range of scenarios with different levels of greenhouse gases. Carter (2008) assumes that any future increase in greenhouse gas concentrations will have no significant impact on global average temperature. He claims that "only minor warming will result from further increases in atmospheric carbon dioxide above the assumed pre-industrial level of about 280 ppm". As noted in a previous section, Carter (2008) reaches this conclusion by choosing an extremely low figure for equilibrium climate sensitivity that is not supported by the evidence documented in the scientific literature.

He cites a few comments about the uncertainties in and limitations of climate models, and includes quotes which he attributes to an entry on a blog by Kevin Trenberth (2007), head of the climate analysis section at the National Center for Atmospheric Research in Boulder, Colorado, USA. But by selectively omitting key parts of the text of the blog, he gives a misleading impression of Trenberth's views. For instance, Carter (2008) ignores the final passages from Trenberth (2007):

"The IPCC report makes it clear that there is a substantial future commitment to further climate change even if we could stabilize atmospheric concentrations of greenhouse gases.

And the commitment is even greater given that the best we can realistically hope for in the near term is to perhaps stabilize emissions, which means increases in concentrations of long-lived greenhouse gases indefinitely into the future. Thus future climate change is guaranteed. So if the science is settled, then what are we planning for and adapting to? A consensus has emerged that "warming of the climate system is unequivocal" to quote the 2007 IPCC Fourth Assessment Working Group I and the science is convincing that humans are the cause. Hence mitigation of the problem: stopping or slowing greenhouse gas emissions into the atmosphere is essential. The science is clear in this respect. However, the science is not done because we do not have reliable or regional predictions of climate. But we need them. Indeed it is an imperative! So the science is just beginning. Beginning, that is, to face up to the challenge of building a climate information system that tracks the current climate and the agents of change, that initializes models and makes predictions, and that provides useful climate information on many time scales regionally and tailored to many sectoral needs. We will adapt to climate change. The question is whether it will be planned or not? How disruptive and how much loss of life will there be because we did not adequately plan for the climate changes that are already occurring?"

Crucially, Carter (2008) also neglects to refer to the following statement from Trenberth (2007):

"The current projection method works to the extent it does because it utilizes differences from one time to another and the main model bias and systematic errors are thereby subtracted out. This assumes linearity. It works for global forced variations, but it can not work for many aspects of climate, especially those related to the water cycle."

Trenberth (2010) further elaborated on this point in an article about the IPCC Fifth Assessment Report:

"In previous IPCC assessments, changes in the atmospheric concentrations of greenhouses gases and aerosols over time were gauged using 'idealized emissions scenarios', which are informed estimates of what might happen in the future under various sets of assumptions related to population, lifestyle, standard of living, carbon intensity and the like. Then the changes in future climate were simulated for each of these scenarios. The output of such modelling is usually referred to as a projection, rather than a prediction or a forecast. Unlike a weather prediction, the models in this case are not initialized with the current or past state of the climate system, as derived from observations. Instead, they begin with arbitrary climatic conditions and examine only the change in projected climate, thereby removing any bias that could be associated with trying to realistically simulate the current climate as a starting point. This technique works quite well for examining how the climate could respond to various emissions scenarios in the long term."

Yet Carter (2008) cites Trenberth (2007) to justify his unsubstantiated conclusion that "it is clear that deterministic GCMs do not produce predictive outputs that are suitable for direct application in policy making; it is therefore inappropriate to use IPCC projections for planning, or even precautionary, purposes as if they were real forecasts of future climate".

IPCC (2007a) presented projections for rises in global average temperature by 2090-2099 compared with 1980-1999 (see Table 1). The projection for the lowest emissions scenario indicated a rise in global average temperature of between 1.1 and 2.9°C, while for the highest emissions scenario the projected range was 2.4 to 6.4°C. IPCC (2007a) concluded:

"Continued greenhouse gas emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would *very likely* [i.e. >90% probability] be larger than those observed during the 20th century".

Potential impacts of future climate change

As noted in previous sections, Carter (2008) completely excludes the probability of rises of more than 1°C no matter what concentration of greenhouse gases occurs in the atmosphere, by disregarding the available scientific literature. This inevitably means that he is unable to properly represent the potential impacts of future climate change.

Carter (2008) claims that future rises in global average temperature would not be harmful on the following grounds: "First because any mild warming caused by enhanced carbon dioxide is likely to be of net climatic benefit; and, second, because higher atmospheric carbon dioxide both enhances plant growth and aids efficiency of water use (Eamus 1996)". In fact, Eamus (1996) pointed out:

"The lack of a decline in g [stomatal conductance] in response to CO_2 enrichment, coupled with the almost invariable increase in leaf area that occurs, requires a significant rise in water use per tree. Such a result contradicts the often cited conclusion that trees growing in a CO_2 enriched environment may exhibit decreased sensitivity, or experience decreased exposure, to drought. In environments where water is limiting to growth, such a lack of response of stomata may increase exposure to drought."

In a more recent review of the evidence about the impact of climate change on water use by vegetation in Australia, Macinnis-Ng and Eamus (2009) concluded:

"Climate change will cause hotter, driers conditions with less rainfall across the majority of the Australian continent. While most ecosystems are already well adapted to water-limitation, the further reduction of water availability coupled with increased atmospheric water demands will have a significant impact on vegetation water use. Transpiration will decline due to reduced rainfall causing reduced soil moisture. Vegetation water use plays a major part in the hydrological cycle with between 70 and 95% of rainfall lost as evapotranspiration. As rainfall decreases, the proportion of rainfall used in evapotranspiration increases, reducing the water yield available for human consumption. Reduction in available water supplies also threatens the quality of water through changes in water chemistry. Current practices in water use are not sustainable and more water efficient practices need to be developed to avoid a water crisis."

This is consistent with the findings of IPCC (2007a):

"Plant growth can be stimulated by increased atmospheric CO_2 concentrations and by nutrient deposition (fertilization effects). However, most experiments and studies show that such responses appear to be relatively short lived and strongly coupled to other effects such as availability of water and nutrients."

Of course, by ignoring the potential impacts of rising temperature and other effects, Carter (2008) disregards most of the likely consequences of climate change. For instance, IPCC (2007a) provided estimates of a range of global sea level rise for each of the emissions scenarios, ranging from 18 to 38 cm by the end of the century for the lowest projection and

26 to 59 cm for the highest (see Table 1). IPCC (2007a) noted that the sea level estimates did not include "uncertainties in climate-carbon cycle feedback" or "the full effects of changes in ice sheet flow".

IPCC (2007b) concluded: "Observational evidence from all continents and most oceans show that many natural systems are being affected by regional climate changes, particularly temperature increases". It noted that "other effects of regional climate changes on natural and human environments are emerging, although many are difficult to discern due to adaptation and non-climatic drivers", but pointed out that "magnitudes of impact can now be estimated more systematically for a range of possible increase in global average temperature" (see Figure 4).

IPCC (2007b) concluded: "Impacts of climate change will vary regionally but, aggregated and discounted to the present, they are very likely to impose net annual costs which will increase over time as global temperatures increase". However, it also added:

"Even the most stringent mitigation efforts cannot avoid further impacts of climate change in the next few decades, which makes adaptation essential, particularly in addressing near-term impacts. Unmitigated climate change would, in the long term, be likely to exceed the capacity of natural, managed and human systems to adapt.

"This suggests the value of a portfolio or mix of strategies that includes mitigation, adaptation, technological development (to enhance both adaptation and mitigation) and research (on climate science, impacts, adaptation and mitigation). Such portfolios could combine policies with incentive-based approaches, and actions at all levels from the individual citizen through to national governments and international organizations."

Conclusions

This paper describes some of the many serious and significant flaws in Carter (2008). Although there are many other glaring mistakes in Carter (2008) those that are described here clearly show that he gives a misleading impression of the findings and views of mainstream researchers, particularly the authors of the reports of the IPCC.

One of the many ironies on display in Carter (2008) is his constant reference to mainstream researchers as "alarmists" while complaining that "unsolicited *ad hominem* attacks are made on qualified persons who espouse different views, and who are often disparaged as 'sceptics', 'deniers', or worse". His paper reads like a piece of crude political propaganda, rather than "a critical account of the scientific arguments that have been claimed as evidence for dangerous, human-caused global warming". In summary, Carter (2008) is possibly the most inaccurate and misleading article about climate change that has ever been published by a journal.

References

Academia Brasileira de Ciéncias, Royal Society of Canada, Chinese Academy of Sciences, Académie des Sciences, Deutsche Akademie der Naturforscher Leopoldina, Indian National Science Academy, Accademia Nazionale dei Lincei, Science Council of Japan, Academia Mexicana de Ciencias, Russian Academy of Sciences, Academy of Science of South Africa, Royal Society and National Academy of Sciences (2007). *Joint science academies' statement on growth and responsibility: sustainability, energy efficiency and climate*

protection. http://royalsociety.org/Joint-science-academies-statement-sustainability-energy-efficiency-and-climate-protection/ (last accessed: 13 July 2010).

Academia Brasileira de Ciéncias, Royal Society of Canada, Chinese Academy of Sciences, Académie des Sciences, Deutsche Akademie der Naturforscher Leopoldina, Indian National Science Academy, Accademia Nazionale dei Lincei, Science Council of Japan, Academia Mexicana de Ciencias, Russian Academy of Sciences, Academy of Science of South Africa, Royal Society and National Academy of Sciences (2008). *Joint Science Academies' Statement: Climate Change Adaptation and the Transition to a Low Carbon Society*. http://royalsociety.org/Joint-science-academies-statement-Climate-change-adaptation-and-the-transition-to-a-low-carbon-society/ (last accessed: 13 July 2010).

Academia Brasileira de Ciéncias, Royal Society of Canada, Chinese Academy of Sciences, Académie des Sciences, Deutsche Akademie der Naturforscher Leopoldina, Indian National Science Academy, Accademia Nazionale dei Lincei, Science Council of Japan, Academia Mexicana de Ciencias, Russian Academy of Sciences, Academy of Science of South Africa, Royal Society and National Academy of Sciences (2009). *G8+5 Academies' joint statement: Climate change and the transformation of energy technologies for a low carbon future*. http://royalsociety.org/Joint-Academies-statement-Climate-change-and-the-transformation-of-energy-technologies-for-a-low-carbon-future/ (last accessed: 13 July 2010).

Akerman, P. (2006). Stern's report scare-mongering. *The Sunday Telegraph*, 5 November. http://www.dailytelegraph.com.au/news/opinion/sterns-report-scare-mongering/story-e6frezz0-1111112469535 (last accessed: 13 July 2010).

Anderegg, W.R.L., Prall, J.W., Harold, J. and Schneider, S.H. (2010). Expert credibility in climate change. *Proceedings of the National Academy of Sciences of the United States of America*, 107: 12107-12109, doi: 10.1073/pnas.1003187107.

Arrhenius, S. (1896). On the influence of carbonic acid in the air upon the temperature of the ground. *Philosophical Magazine and Journal of Science*, Series 5, 41: 237-276.

Brohan, P., Kennedy, J.J., Harris, I., Tett, S.F.B. and Jones P.D. (2006). Uncertainty estimates in regional and global observed temperature changes: a new data set from 1850. *Journal of Geophysical Research*, 111, D12106. doi: 10.1029/2005JD006548.

Bowen, A. and Ranger, N. (2009). *Mitigating climate change through reductions in greenhouse gas emissions: the science and economics of future paths for global annual emissions*. Policy brief, December 2009, Grantham Research Institute on Climate Change and the Environment and Centre for Climate Change Economics and Policy. 43pp. http://www2.lse.ac.uk/GranthamInstitute/publications/PolicyBriefsandPapers/PBMitigatingBowenRangerDec09.pdf (last accessed on 20 July 2010).

Burgess, E. (1837). English translation of Fourier, J.-B.J. (1824) 'Remarques générales sur les températures du globe terrestre et des espaces planetaires' (In: *Annales de Chimie et de Physique*. 2nd ser., 27:136-167). *American Journal of Science*, 32: 1-20.

Carter, R.M. (2008). Knock knock: Where is the evidence for dangerous human-caused global warming? *Economic Analysis & Policy*, 38: 177-202.

Connor, S. (2010). Fabricated quote used to discredit climate scientist. *The Independent*, 10 February. http://www.independent.co.uk/environment/climate-change/fabricated-quote-used-to-discredit-climate-scientist-1894552.html (last accessed: 13 July 2010).

Damon, P.E. and Laut, P. (2004). Pattern of strange errors plagues solar activity and terrestrial climate data. *Eos*, 86: 370, 374.

Eamus, D. (1996). Responses of field grown trees to CO_2 enrichment. *The Commonwealth Forestry Review*, 75: 39-47.

Gerlach, T.M. (2010). Volcanic versus anthropogenic carbon dioxide: the missing science. *EARTH*, 55: 87.

Hansen, J., Ruedy, R. and Lo, K. 2010. Global surface temperature change. http://data.giss.nasa.gov/gistemp/paper/gistemp2010_draft0601.pdf (last accessed: 14 July 2010).

Hegerl, G.C., Zwiers, F.W., Braconnot, P., Gillett, N.P., Luo, Y., Marengo Orsini, J.A., Nicholls, N., Penner, J.E. and Stott, P.A. (2007). Understanding and attributing climate change. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller, Eds.), Cambridge University Press, Cambridge, UK. 663-745.

Hieb, M. (2003). *Water Vapor Rules the Greenhouse System*. http://www.geocraft.com/WVFossils/greenhouse_data.html (last accessed 21 July 2010).

Houghton, J.T. (1994). *Global Warming: The Complete Briefing*. First edition. Lion Publishing plc. London, UK. 351pp.

Houghton, J.T. (2010). Global warming: Sceptics are putting words in my mouth. *The Observer*, 14 February. http://www.guardian.co.uk/theobserver/2010/feb/14/climate-change-scepticism-robin-mckie (last accessed: 13 July 2010).

Hulme, M., Zorita, E., Stocker, F.M., Price, J. and Christy, J.R. (2010). IPCC: cherish it, tweak it or scrap it? Opinion, *Nature*, 463: 730-732. doi: 10.1038/463730a.

InterAcademy Council (2010) *Climate Change Assessments: Review of the Processes and Procedures of the IPCC*. http://reviewipcc.interacademycouncil.net/report/Climate%20Change%20Assessments,%20Review%20of%20the%20Processes%20&%20Procedures%20of%20the%20IPCC.pdf (last accessed: 8 September 2010).

Intergovernmental Panel on Climate Change (2006). *Principles Governing IPCC Work*. Geneva, Switzerland. http://www.ipcc.ch/pdf/ipcc-principles/ipcc-principles.pdf (last accessed: 13 July 2010).

Intergovernmental Panel on Climate Change (2007a). *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller, Eds.), Cambridge University Press, Cambridge, UK. 996pp.

Intergovernmental Panel on Climate Change (2007b). *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds.), Cambridge University Press, Cambridge, UK. 976pp.

Intergovernmental Panel on Climate Change (2007c). *Climate Change 2007: Mitigation of Climate Change. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (B. Metz, O.R. Davidson, P.R. Bosch, R. Dave and L.A. Meyer, Eds.), Cambridge University Press, Cambridge, UK. 851pp.

Intergovernmental Panel on Climate Change (2010). *IPCC statement on the melting of Himalayan glaciers*. Geneva, Switzerland. http://www.ipcc.ch/pdf/presentations/himalaya-statement-20january2010.pdf (last accessed: 13 July 2010).

Kiehl, J.T. and Trenberth, K.E. (1997). Earth's annual global mean energy budget. *Bulletin of the American Meteorological Society*, 78:197-208.

Liebmann, B., Dole, R.M., Jones, C., Bladé, I. and Allured, D. (2010). Influence of choice of time period on global surface temperature trend estimates. *Bulletin of the American Meteorological Society*, early online release. doi: 10.1175/2010BAMS3030.1.

Macinnis-Ng, C. and Eamus, D. (2009). *Climate change and water use of native vegetation*. Land & Water Australia. 19pp.

http://lwa.gov.au/files/products/innovation/pn30134/pn30134_0.pdf (last accessed on 20 July 2010).
McCright, A.M. and Dunlap, R.E. (2003). Defeating Kyoto: The Conservative movement's impact on US climate change policy. *Social Problems*, 50: 348-373.
McCright, A.M. and Dunlap, R.E. (2010). Anti-reflexivity: The American Conservative movement's success in undermining climate science and policy. *Theory, Culture and Society*, 27: 100-133, doi: 10.1177/0263276409356001.
Monckton, C. (2006). *Gore Gored*. CCSP Reprint Series. The Center for Science and Public Policy, Washington DC. http://ff.org/centers/csspp/pdf/20061121_gore.pdf (last accessed: 13 July 2010).
National Climatic Data Center (2010). State of the Climate Global Analysis: July 2010. http://www.ncdc.noaa.gov/sotc/?report=global&year=2010&month=7 (last accessed 9 September 2010).
National Research Council (2006). Surface Temperature Reconstructions for the Last 2,000 Years. The National Academies Press, Washington, DC, USA. 160pp.
National Research Council (2010). Advancing the Science of Climate Change. The National Academies Press, Washington DC, USA. 506 pp. http://www.nap.edu/catalog.php?record_id=12782#toc (last accessed on 14 July 2010).
Oreskes, N. (2004). Beyond the ivory tower: The scientific consensus on climate change. *Science*, 306: 1686, doi: 10.1126/science.1103618.
Parker, D.E. (2010). Urban heat island effects on estimates of observed climate change. *WIREs Climate Change*, 1:123-133. doi: 10.1002/wcc.021.
PBL (Netherlands Environmental Assessment Agency) (2010). *Assessing an IPCC assessment: An analysis of statements on projected regional impacts in the 2007 report*. The Hague/Bilthoven. 99pp.
Plimer, I. (2009). *Heaven and Earth: Global Warming: The Missing Science*. Quartet Books Ltd, London, UK 503pp.
Smith, T.M., Reynolds, R.W., Peterson, T.C. and Lawrimore, J. (2010). Improvements to NOAA's historical merged land-ocean surface temperature analysis (1880-2006). *Journal of Climate*, 21: 2283-2296. doi: 10.1175/2007JCLI2100.1.
Stott, P.A., Gillett, N.P., Hegerl, G.C., Karoly, D.J., Stone, D.A., Zhang, X. and Zwiers, F. (2010). Detection and attribution of climate change: a regional perspective. *WIREs Climate Change*, 1:192-211. doi: 10.1002/wcc.34.
Tans, P. (2010). Mauna Loa CO_2 annual mean data. NOAA/ESRL. http://www.esrl.noaa.gov/gmd/ccgg/trends/ (last accessed on: 20 July 2010).
Taylor, F.W. (2005). *Elementary Climate Physics*. Oxford University Press, Oxford, UK. 212pp.
Trenberth, K.E. (2007). Predictions of climate. *Climate Feedback: The Climate Change Blog*. http://blogs.nature.com/climatefeedback/2007/06/predictions_of_climate.html (last accessed on 20 July 2010).
Trenberth, K.E. (2010). More knowledge, less certainty. *Nature Reports Climate Change*, 4: 20-21. doi: 10.1038/climate.2010.06.
Tyndall, J. (1861). The Bakerian Lecture: On the absorption and radiation of heat by gases and vapours, and on the physical connexion of radiation, absorption, and conduction. *Philosophical Transactions of the Royal Society of London*, 151: 1-36.
World Meteorological Organization (2010). *WMO statement on the status of the global climate in 2009*. WMO-No. 1055, Geneva, Switzerland. 13pp. http://www.wmo.int/pages/publications/showcase/documents/1055_en.pdf (last accessed on: 13 July 2010).

Figures

Figure 1: Comparison of records of annual global average temperature anomalies (relative to 1961-1990) between 1850 and 2009. The black line represents mean temperature values, with the grey area representing the 95% uncertainty range, from Met Office/Climatic Research Unit record (HadCRUT3). The red line represents mean temperature values from the NOAA NCDC record. The blue line represents mean temperature values from the NASA GISS record. Source: UK Met Office, Crown copyright.

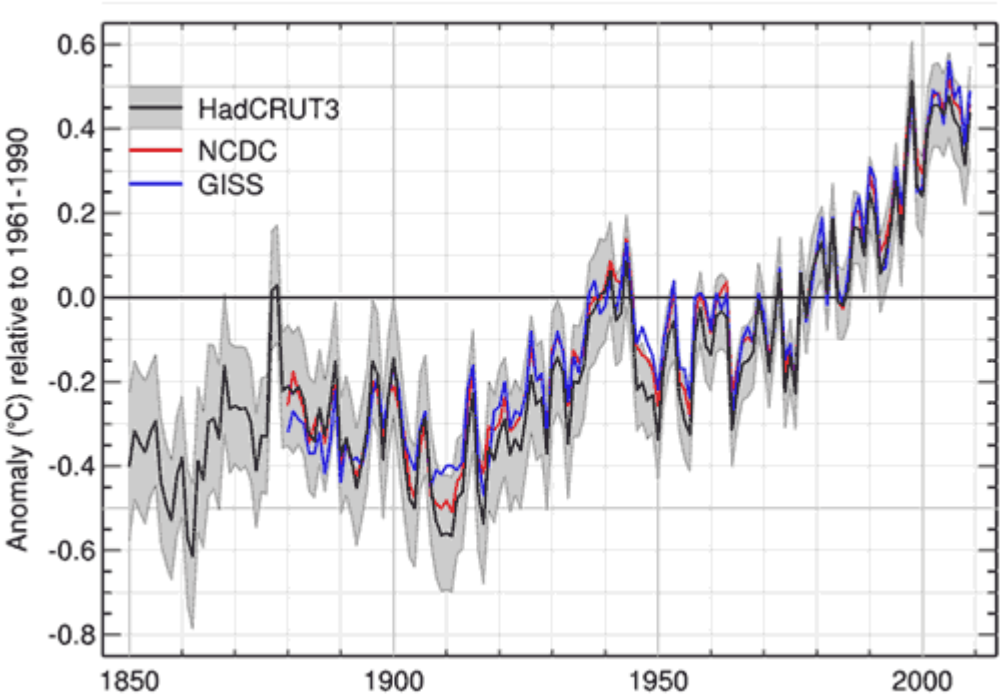

Figure 2: Global average land-surface, sea-surface and combined land- and sea-surface temperature anomalies 1850-2009 from HadCRUT3. The red bars show the global annual average near-surface temperature anomalies (relative to 1961-1990) from 1850 to 2009 for land areas only (top), ocean areas only (middle) and combined land and ocean (bottom). The error bars show the 95% uncertainty range on the annual averages. The thick blue line shows the annual values after smoothing with a 21-point binomial filter. The thin blue lines show the 95% uncertainty range on the smoothed curve. Source: UK Met Office, Crown copyright.

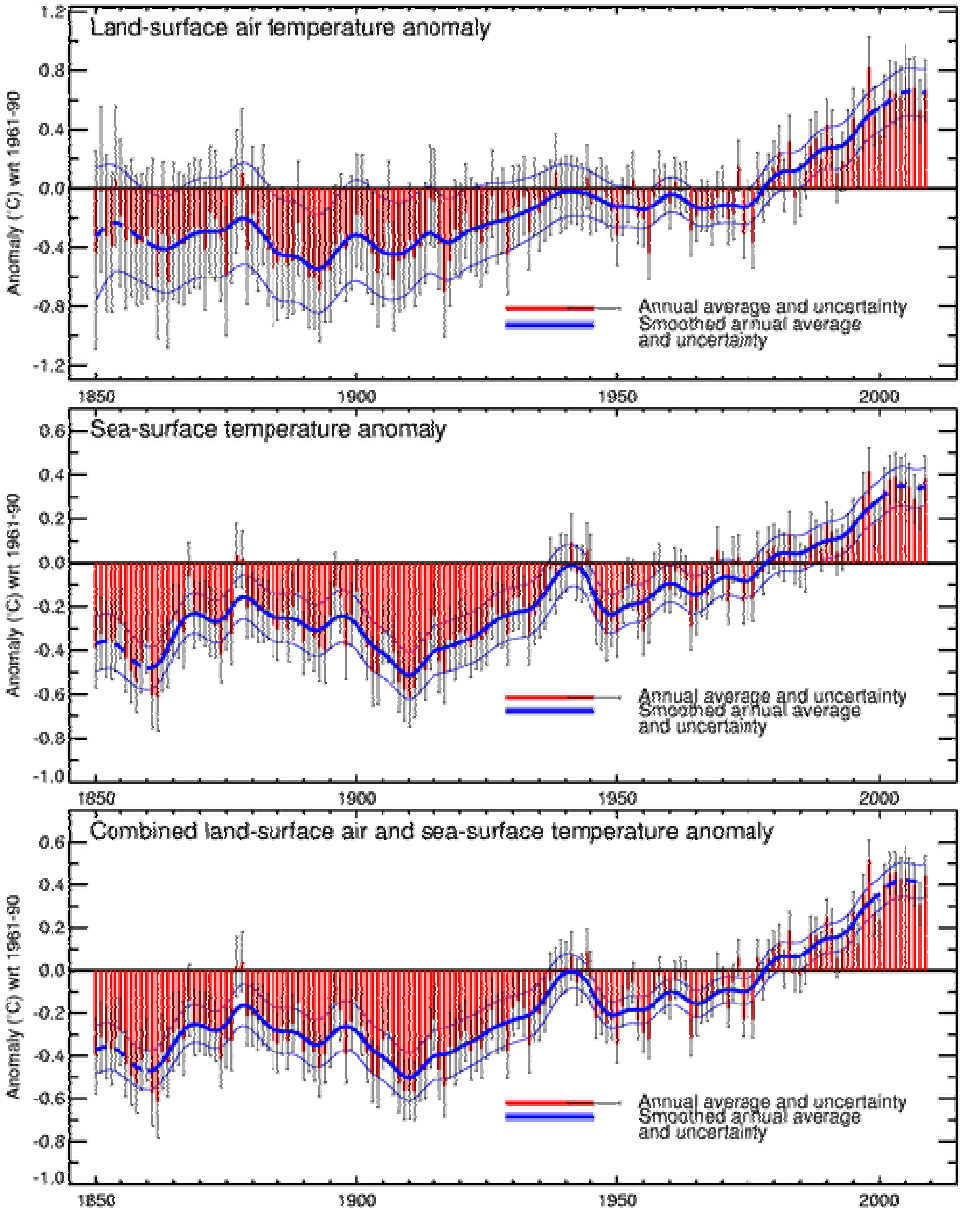

Figure 3: Temperature anomalies (relative to 1961-1990) in the tropical lower stratosphere, tropical lower troposphere and surface, from January 1958 to March 2010. Source: UK Met Office, Crown copyright. HadAT2 radiosonde data and HadCRUT3 surface data are produced by the UK Met Office Hadley Centre. UAH MSU satellite data are produced by the University of Alabama in Huntsville and are available courtesy of John Christy and Roy Spencer. RSS MSU satellite data are produced by Remote Sensing Systems and are available courtesy of Carl Mears.

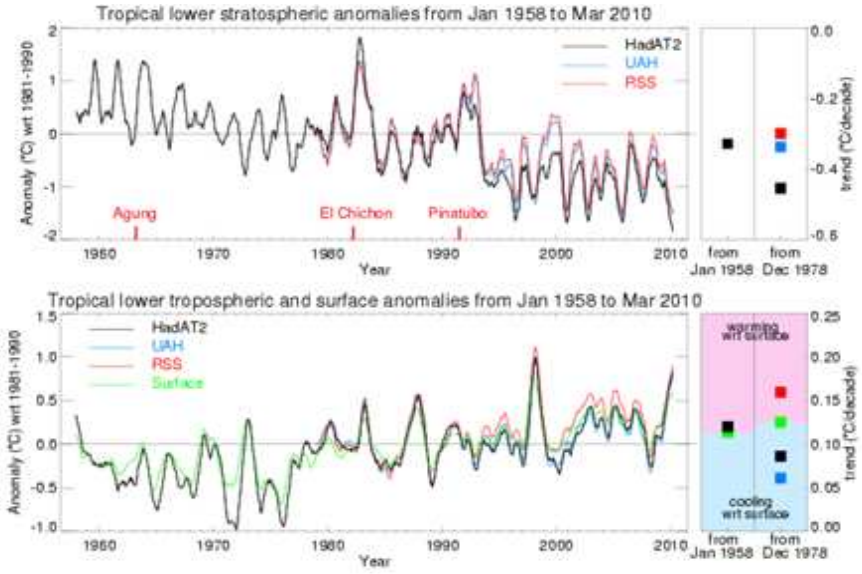

Table1: Projected global average surface warming and sea level rise at the end of the 21st century. Source: IPCC (2007a) Table SPM.3, p.13.

Case	Temperature Change (°C at 2090-2099 relative to 1980-1999)[a]		Sea Level Rise (m at 2090-2099 relative to 1980-1999)
	Best estimate	*Likely* range	Model-based range excluding future rapid dynamical changes in ice flow
Constant Year 2000 concentrations[b]	0.6	0.3 – 0.9	NA
B1 scenario	1.8	1.1 – 2.9	0.18 – 0.38
A1T scenario	2.4	1.4 – 3.8	0.20 – 0.45
B2 scenario	2.4	1.4 – 3.8	0.20 – 0.43
A1B scenario	2.8	1.7 – 4.4	0.21 – 0.48
A2 scenario	3.4	2.0 – 5.4	0.23 – 0.51
A1FI scenario	4.0	2.4 – 6.4	0.26 – 0.59

Table notes:
[a] These estimates are assessed from a hierarchy of models that encompass a simple climate model, several Earth System Models of Intermediate Complexity and a large number of Atmosphere-Ocean General Circulation Models (AOGCMs).
[b] Year 2000 constant composition is derived from AOGCMs only.

Figure 4: Examples of global impacts projected for changes in climate (and sea level and atmospheric carbon dioxide where relevant) associated with different amounts of increase in global average surface temperature in the 21st century. This is a selection of some estimates available for inclusion in IPCC (2007b). All entries are taken from published studies that are referenced in chapters of IPCC (2007b). Edges of boxes and placing of text indicate the range of temperature change to which the impacts relate. Arrows between boxes indicate increasing levels of impacts between estimations. Other arrows indicate trends in impacts. All entries for water stress and flooding represent the additional impacts of climate change relative to the conditions projected across the range of projected scenarios. Adaptation to climate change is not included in these estimations. For extinctions, 'major' means ~40 to ~70% of assessed species. Source: IPCC (2007b), Table TS.3, p.66.