Apocalypse cancelled

Sunday Telegraph, 5 November, 2006

Discussion, calculations and references

Gentle reader,

Thank you very much for doing me the honour of reading my research article on the science of climate change in *The Sunday Telegraph* on 5 November 2006. To assist you in verifying my facts, here are some references and calculations. Please feel free to contact me at monckton@mail.com if you have any questions. I will do my best to answer if I can.

There will be a second article in *The Sunday Telegraph* on 12 November 2006. I hope you will find that article interesting too.

With all good wishes, and renewed thanks for your kind interest,

Monckton of Brenchley

Note by the author

In the *Sunday Telegraph* article for 5 November 2006 and in that which will follow on 12 November, I have done my best to steer between the strongly-held opinions and propaganda statements of climate-change true-believers and contrarians alike. Climate change is an inescapably political issue. I have spent several months reading the leading scientific papers and assessing the arguments put forward, often with passionate conviction, by the protagonists on both sides.

The official case depends crucially on a series of assumptions whose truth has not been demonstrated, some of which are not easily testable. In particular, the temperature effect at the surface of the incompletely-saturated peripheral absorption bands of CO_2 at the tropopause cannot be confidently estimated. Air and sea temperatures have failed to rise anything like as much as "global-warming" theory predicts. Explanations for the shortfall of observed outturn against theoretical projection are mutually inconsistent and scientifically dubious. I conclude that, on the balance of probabilities, the contrarians are significantly closer to the truth than the UN and its supporters. – M of B

Summary of the argument

ALL TEN of the propositions listed below must be proven true if the climate-change "consensus" is to be proven true. The first article considers the first six of the listed propositions and draws the conclusions shown. The second article will consider the remaining four propositions.

Proposition	*Conclusion*
1. That the debate is over and all credible climate scientists are agreed.	**False**
2. That temperature has risen above millennial variability and is exceptional.	**Very unlikely**
3. That changes in solar irradiance are an insignificant forcing mechanism.	**False**
4. That the last century's increases in temperature are correctly measured.	**Unlikely**
5. That greenhouse-gas increase is the main forcing agent of temperature.	**Not proven**
6. That temperature will rise far enough to do more harm than good.	**Very unlikely**
7. That continuing greenhouse-gas emissions will be very harmful to life.	**Unlikely**
8. That proposed carbon-emission limits would make a definite difference.	**Very unlikely**
9. That the environmental benefits of remediation will be cost-effective.	**Very unlikely**
10. That taking precautions, just in case, would be the responsible course.	**False**

Discussion

"Fewer scientific problems are so often discussed, yet so rarely decided by proofs, as whether climatic relations have changed over time." – Joachim von Schouw, 1826.

"Nothing is so fervently believed as that which is not known." – Montaigne.

"When men have ceased to believe in Christianity, it is not that they will believe in nothing. They will believe in anything." – G.K. Chesterton.

"If you will believe that, you will believe anything" – Wellington.

This discussion follows the sequence of the article in the Sunday Telegraph on 5 November 2006. References by name and date in the text of the discussion are listed alphabetically at the end.

"Market failure": Stern (2006a) said: "When people do not pay for the consequences of their actions, we have market failure. This is the greatest market failure the world has seen." Gordon Brown, the Chancellor of the Exchequer, who attended the launch with the Prime Minister, used the same phrase in his remarks. The full text of the Stern Report is online (Stern, 2006b).

Is there a scientific consensus about global warming?

All climate scientists accept that there are more greenhouse gases in the air than there were, and that in consequence the world will warm somewhat. There is no consensus on the central question of how much warming there will be. The main area of dispute is about the magnitude of the temperature effect of carbon dioxide. Arrhenius (1896) was the first to calculate the effect of doubling atmospheric carbon dioxide, concluding that global temperature would rise by 8C.

> In the 1970s, experiments showed that at the Earth's surface the principal absorption bands of atmospheric CO_2 were saturated, and it was thought that a doubling of CO_2 might raise temperature by as little as 0.5C. However, subsequent experiments indicated that in the much thinner air and much lower temperature at the tropopause – the top of the main atmospheric layer, around 5 to 11 miles up – the secondary absorption bands of CO_2 were not fully saturated. Some of the outgoing, long-wave radiation from the Earth's surface would be intercepted at the tropopause and scattered back into the troposphere. The UN's 1990 and 1996 *Assessment Reports* suggested that additional warming of 4.4 watts per square metre per second would occur. The 2001 report cut this figure to 3.7 watts. However, it is not clear how much of this additional energy reaches the surface. A submission to the UN by Dr. Hugh Elsaesser suggested that only 1.5 watts would reach the surface. See also De Laat *et al.* (2004) and Etheridge *et al.* (1996) for a discussion of man's contribution to the greenhouse effect.

Leading climate scientists who strongly disagree with the view that additional carbon dioxide in the air will have the large effect on the climate suggested by the UN include Professor Richard Lindzen of the Massachusetts Institute of Technology, who recently received a £10,000 prize for courage in opposing conventional thinking. Some 41 scientists recently wrote to the *Telegraph* to say they were not part of, and were not convinced by, the "global warming" consensus.

Contrarians and the fossil fuel lobby: The Royal Society, in a current pamphlet entitled "A guide to facts and fictions about climate change", says: "There are some individuals and organizations, some of which are funded by the US oil industry, that seek to undermine the science of climate change and the work of the [UN] Intergovernmental Panel on Climate Change."

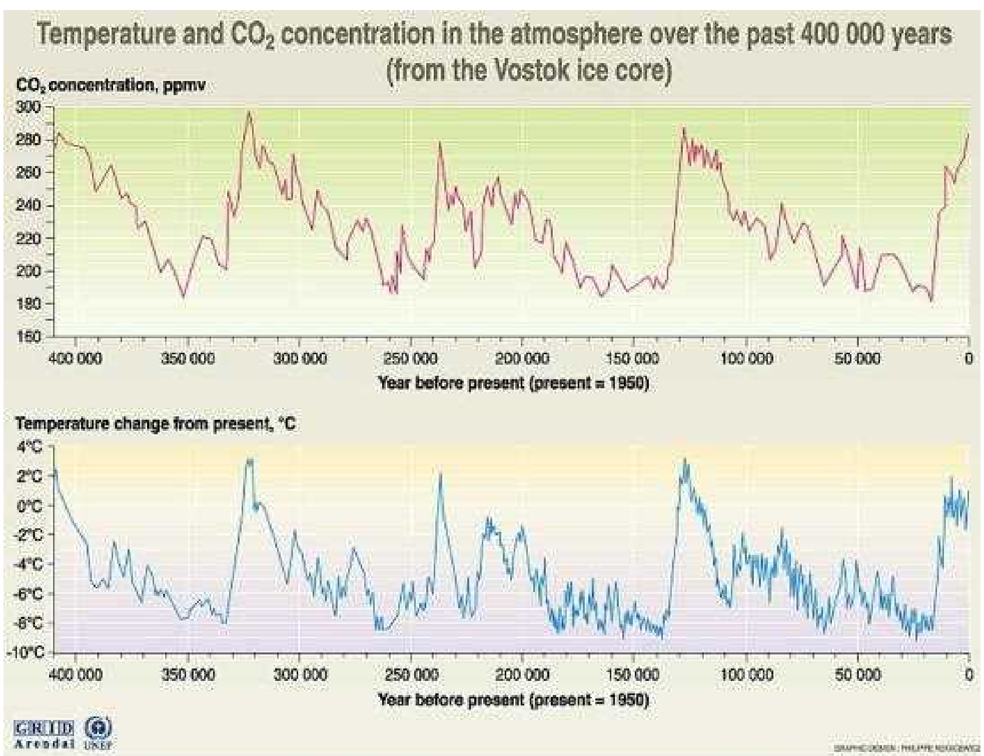
Environmentalists say that Exxon Mobil, in particular, has provided funding to organizations that disagree with the "consensus" view on climate change. See, for example, www.exxonsecrets.org.

On the other hand, the Royal Society is subsidized by the UK Government, and most scientists worldwide are State-funded. It has been said that the fundamental equation of State-subsidized science is **"No Problem Equals No Funding".** The *Sunday Telegraph* article intentionally avoids point-scoring of this kind, on either side of the debate, and is directed not *ad hominem* but *ad rem.*

UK funding of the UN's technical panel on climate change: The UN's documents occasionally acknowledge the British Government's funding.

Did rising carbon dioxide end the Ice Ages?

The double graph, reproduced below lists CO_2 concentration above temperature: but, if the two graphs were superimposed at sufficient scale, as is customary when comparing such similar curves, changes in temperature would be seen to *precede* changes in CO_2 concentration by 400 to 4,000 years. Petit *et al.* (1999) state that during each of the last four interglacial periods the Earth was warmer than the current warm period:



Source: J.R. Petit, J. Jouzel, et al. Climate and atmospheric history of the past 420 000 years from the Vostok ice core in Antarctica, Nature 399 (3June), pp 429-436, 1999.

Was there a mediaeval warm period?

"We have to get rid of the mediaeval warm period": Deming (1995) brought himself to the attention of the palaeoclimatological community by his analysis of North American borehole temperatures published in *Science*. Deming (2005) gives the quotation in the *Sunday Telegraph* article. Deming refers to *State of Fear* (Crichton, 2004), a best-selling techno-thriller giving an influential, sceptical and thoroughly-referenced account of the climate-change debate.

Were mediaeval temperatures at least as high as today's? This question is central to answering the question whether "global warming" is or will become dangerous to the planet.

Until the UN's 2001 report, the existence of a warm period of about 500 years between c.950 and c.1450 AD had not been controversial. The mediaeval warm period formed part of a natural cycle of climatic variations that had been apparent since the end of the last Ice Age ~12,000 years ago.

According to Villalba (1990, 1994), and Soon & Baliunas (2003), the mediaeval warm period was warmer than the current warm period by up to 3C. From c.1000 AD, ships were recorded as having sailed in parts of the Arctic where there is a permanent ice-pack now (Thompson *et al.* 2000; Briffa 2000; Lamb 1972a, b; Villalba 1990, 1994).

In 1421 a Chinese Imperial Navy squadron sailed right round the Arctic and found no ice anywhere. It is possible that at that time there was less of an icecap at the North Pole than there is now, particularly in summer. Yet the polar bears survived. Though there has been much discussion of the supposed threat posed by the warmer Arctic, the polar bears are thriving in the current warm period. Eleven of the thirteen principal known families are prospering as never before.

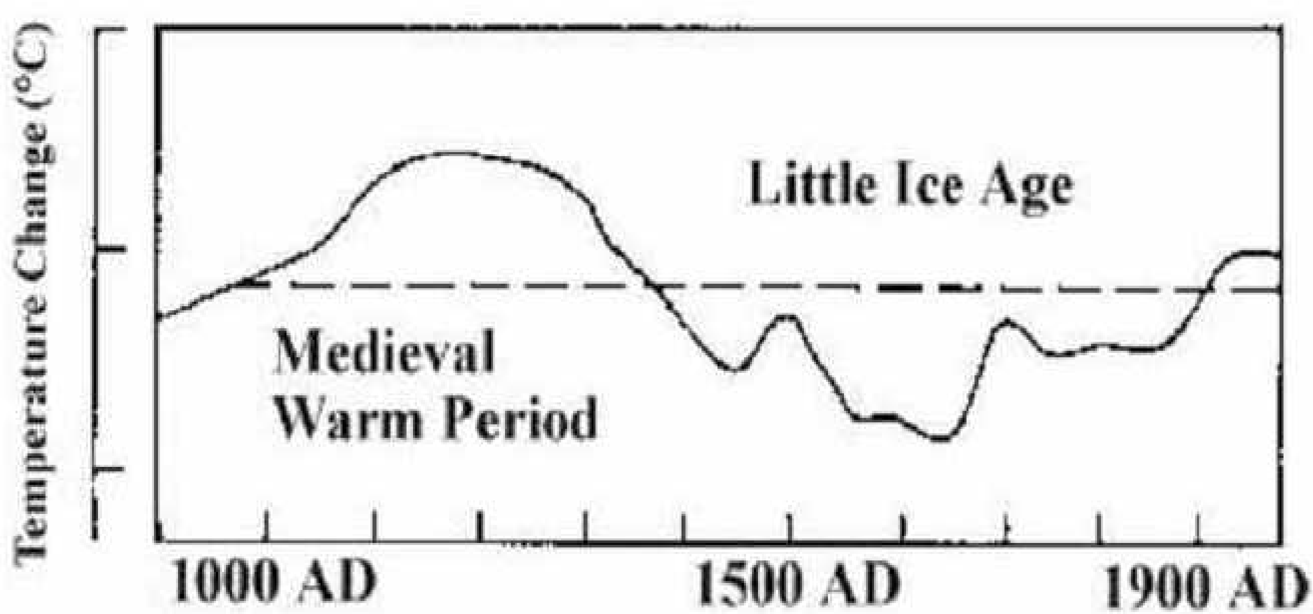
Greenland in the Middle Ages: Eric the Red had named Greenland "Greenland" to encourage Danish settlers, because in his time south-western Greenland was indeed green. It was ice-free, and was extensively cultivated until c.1425 AD, when the farms were suddenly overrun by permafrost.

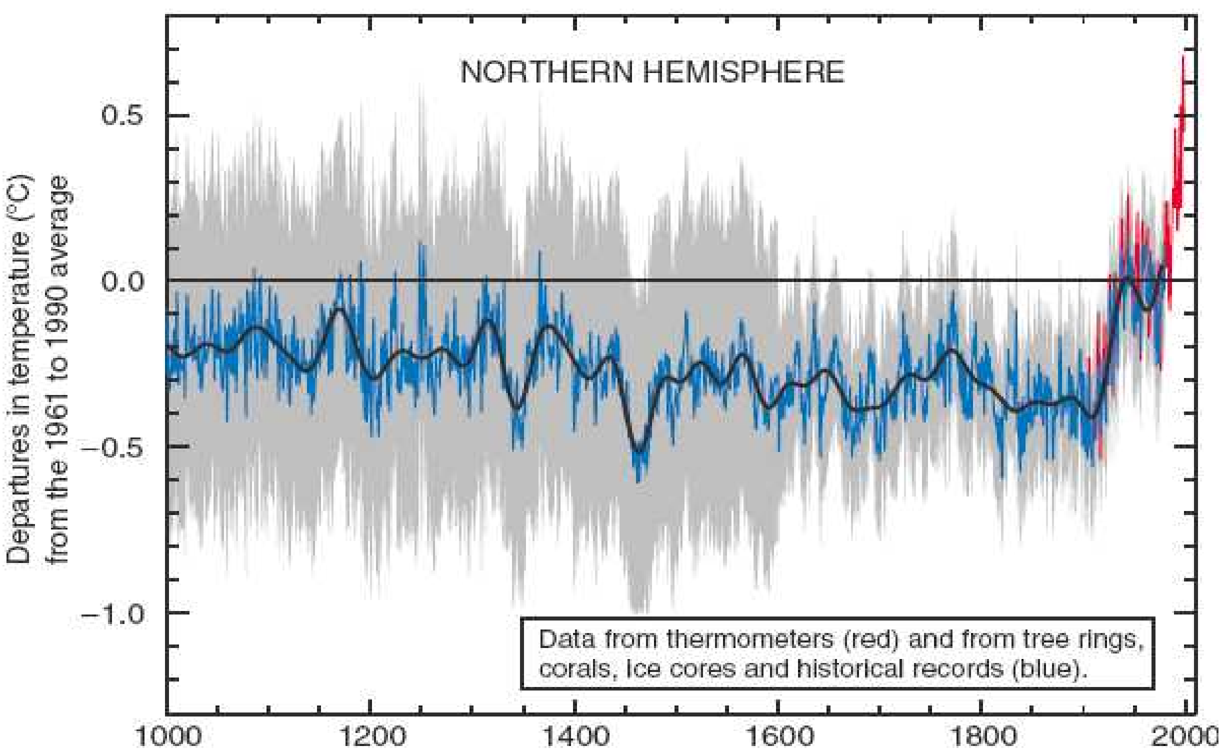
The Viking agricultural settlements remain under permafrost to this day – a powerful indication that the Middle Ages were warmer than the present, and that there is little cause for alarm at the current melting of Greenland glaciers because they are very likely to have melted to more than their present extent during the mediaeval warm period.

The "little ice age": The mediaeval warm period was followed by a 300-year "little ice age" until c.1750 AD. At the beginning of this period, mean temperatures dropped by 1.5C in 100 years. The coldest period was c.1550 to 1700 (Jones *et al.* 1998; Villalba 1990, 1994). Frost fairs were held on the frozen River Thames in London.

Not only is the mediaeval warm period not shown on the UN's graph of temperature over the past 1000 years: the Little Ice Age is also absent.

From c. 1750, temperatures rose and held steady until the late Victorian era. These temperature fluctuations were not caused by humankind's activities. The UN's 1996 report included a graph illustrating them. By the time of the 2001 report, the UN had eradicated the mediaeval warm period:

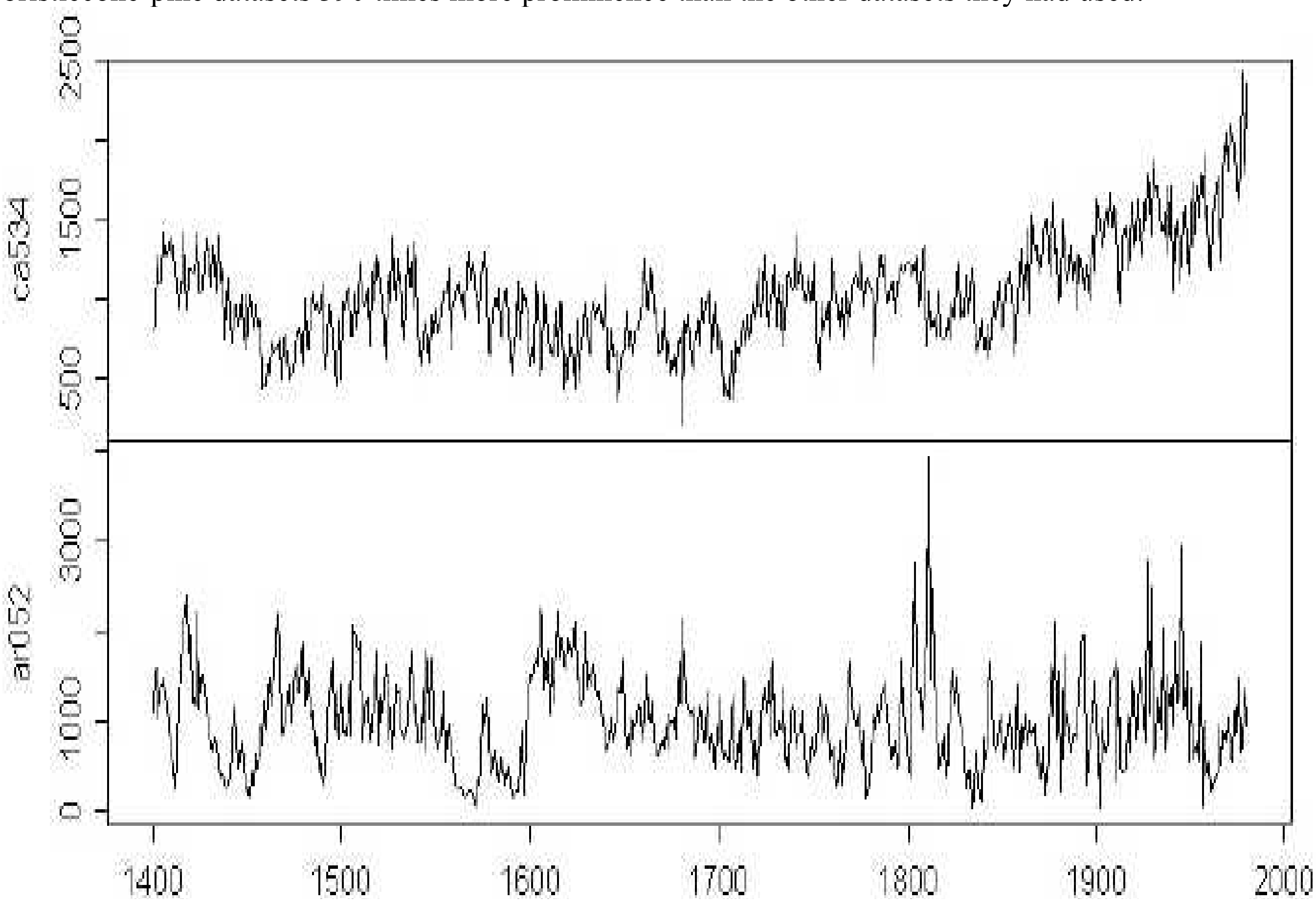




Upper graph: *Temperature history from UN 1996 report, showing the mediaeval warm period.*
Lower graph*:"Hockey-stick" from UN 2001 report. The mediaeval warm period is absent.*

The UN's 2001 graph, variously known as the "hockey-stick" or "foxtail" or "J-curve", had first appeared in *Nature* (Mann *et al.,* 1998) and, the following year, in *Geophysical Review Letters* (Mann *et al.,* 1999). After its appearance in the UN's 2001 report, McIntyre *et al.* (2003, 2005) demonstrated that the erasure of the mediaeval warm period in the 2001 graph had been caused by inappropriate data selection and incorrect use of statistical methods.

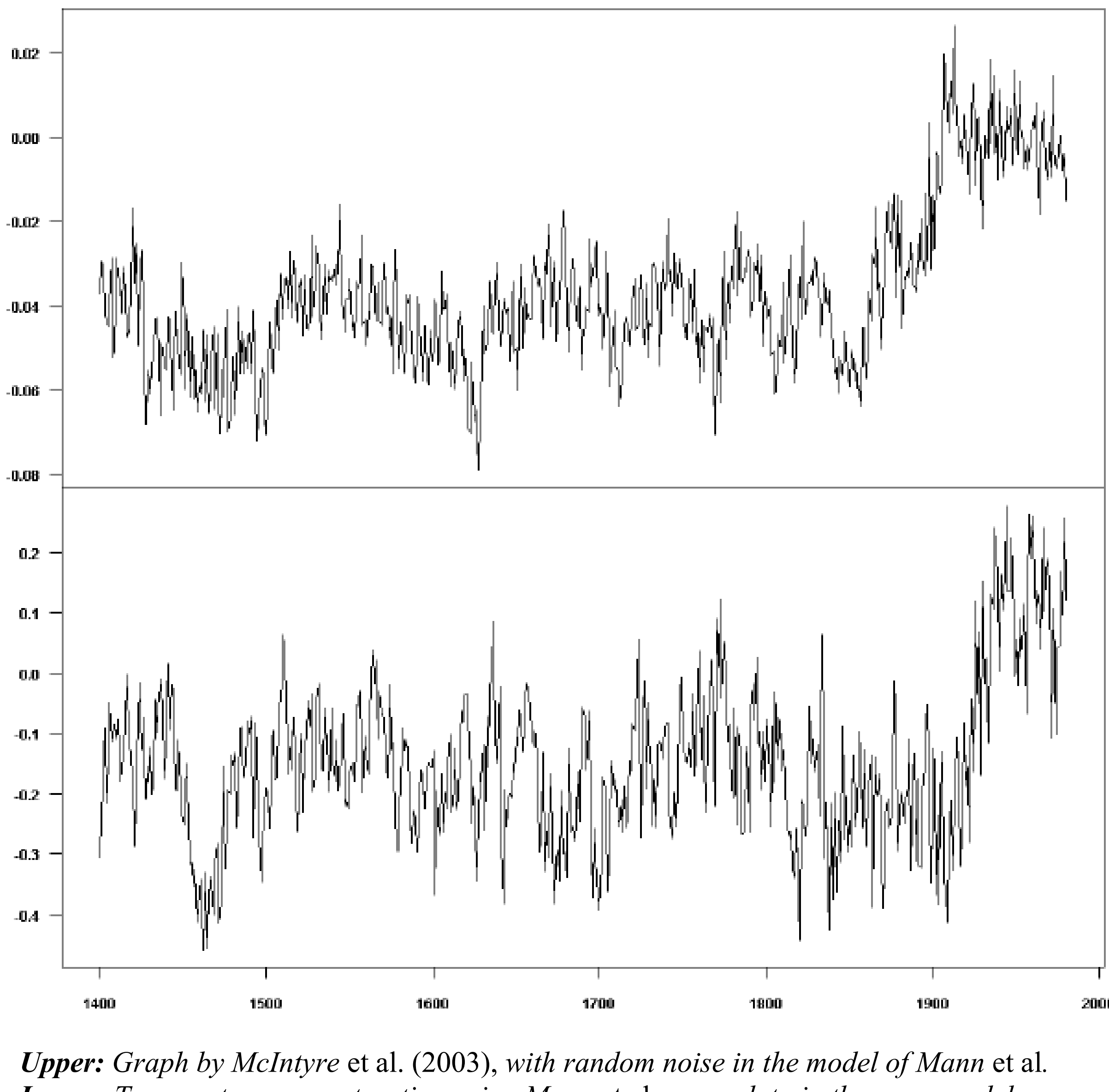
The first mistake made by Mann *et al.* and copied by the UN in 2001 lay in the choice of proxy data. The UN's 1996 report had recommended against reliance upon bristlecone pines as proxies for reconstructing temperature, because 20th-century carbon-dioxide fertilization accelerated annual growth and caused a false appearance of exceptional recent warming. Notwithstanding the warning against reliance upon bristlecones in UN 1996, Mann *et al.* had relied chiefly upon a series of bristlecone-pine datasets for their reconstruction of mediaeval temperatures. Worse, their statistical model had given the bristlecone-pine datasets 390 times more prominence than the other datasets they had used:



Two tree ring chronologies from the dataset relied upon by Mann et al (1998). ***Upper panel:*** *Sheep Mountain, California, USA.* ***Lower panel:*** *Mayberry Slough, Arizona, USA. Both series are the same length, but Mann's algorithm gives the Sheep Mountain chronology 390 times the weight of the other series.*

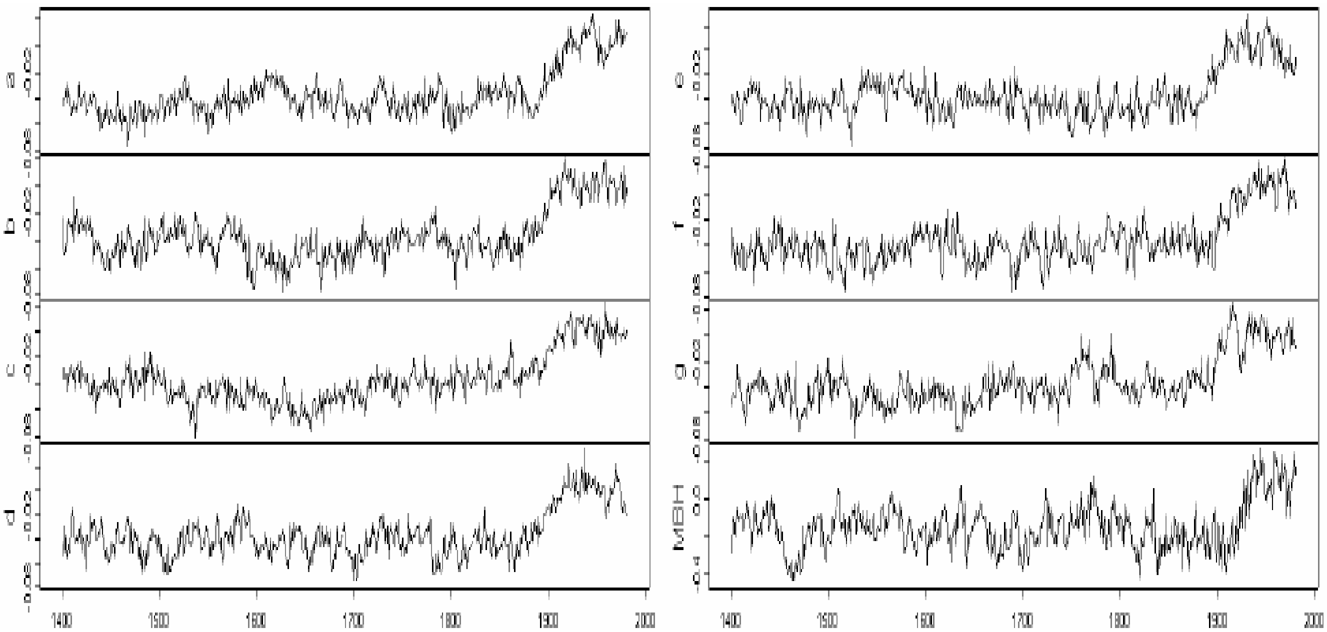
To McIntyre *et al.,* it appeared possible that Mann *et al.* had given the tainted bristlecone data series such exceptional prominence, effectively swamping all influence from the other datasets in their calculations, because the bristlecone-pine dataset produced the pronounced 20th-century uptick (and a corresponding suppression of evidence for mediaeval high temperatures), which would apparently eradicate the mediaeval warm period.

To test this possibility, McIntyre *et al.* ran the algorithm of Mann *et al.* 10,000 times, having replaced all palaeoclimatological data with randomly-generated, electronic "red noise". They found that – even with this entirely random data, altogether unconnected with the temperature record – the model nearly always constructed a "hockey-stick" curve similar to that in the UN's 2001 report:

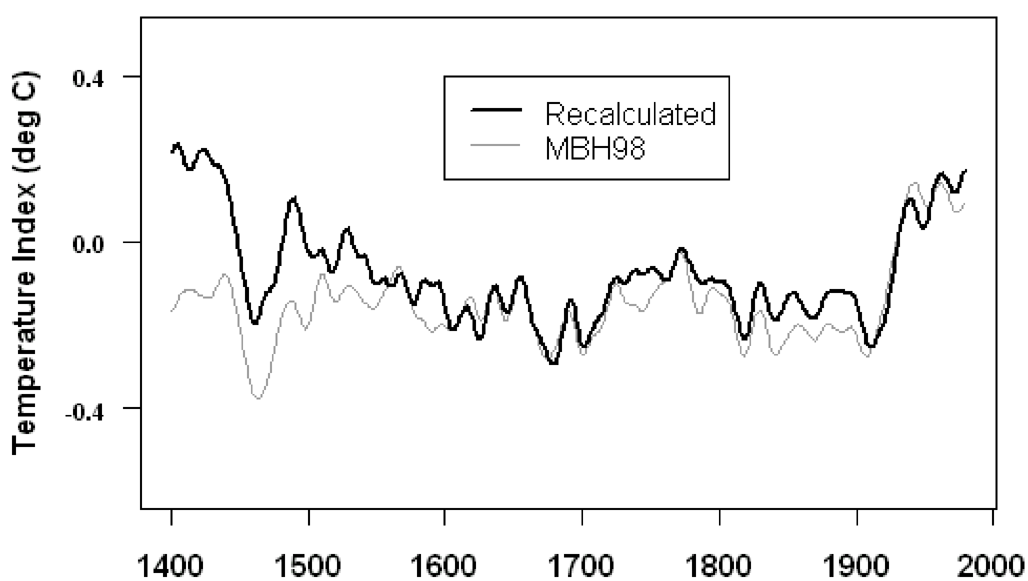


Upper: *Graph by McIntyre* et al. (2003), *with random noise in the model of Mann* et al.
Lower: *Temperature reconstruction using Mann* et al. *proxy data in the same model.*

Further to illustrate the point, McIntyre *et al.* generated graphs using the Mann *et al.* algorithm seven times using random red noise and added Mann's graph compiled from the proxy temperature datasets. It is not easy to see which graph is generated from the proxy data as opposed to the random noise:



McIntyre *et al.* (2003, 2005) also tested the algorithm of Mann *et al.* (1998, & UN, 2001) without the bristlecone-pine data, whereupon the mediaeval warm period reappeared. They also found that Mann *et al.* had excluded from their calculations a single dataset covering the later mediaeval warm period, which had been stored in a computer file marked "**CENSORED_DATA**". McKitrick *et al.* ran the Mann *et al.* model including the missing dataset, and again found that the mediaeval warm period reappeared:



Recalculation of the temperature reconstruction of Mann et al. *("MBH98") by McIntyre* et al.

Several eminent scientists have commented on the work of McIntyre and McKitrick. For instance, Philip Muller (2004), a physicist at Berkeley, said that the two Canadian scientists' work –

> "…hit me like a bombshell, and I suspect it is having the same effect on many others. Suddenly the hockey stick, the poster-child of the global warming community, turns out to be an artifact of poor mathematics."

Dr. Rob van Dorland, of the Dutch National Meteorological Agency, has said:

> "It is strange that the climate reconstruction of Mann passed both peer review rounds of the IPCC without anyone ever really having checked it."

In February 2005 the German television channel *Das Erste* interviewed Ulrich Cubasch, a climatologist, who said that he had been unable to reproduce the Mann *et al.* "hockey-stick" graph, whereupon he –

> "… discussed the objections with his colleagues, and sought to work them through. … Bit by bit, it became as clear to his colleagues as it had to him: the two Canadians were right. … Between 1400 and 1600, the temperature shift was considerably higher than, for example, in the previous century. With that, the core conclusion, and also that of the entire IPCC 2001 Report, was completely undermined."

Dr. Hendrik Tennekes, director emeritus of the Royal Meteorological Institute of the Netherlands, wrote to Dr. McIntyre in 2005 to say:

> "The IPCC review process is totally flawed. … The scientific basis for the Kyoto Protocol is grossly inadequate."

However, the fact that the central graph of the UN's 2001 report was defective has not had anything like as much attention from the media as the stories of impending disaster which politicians – and the UN itself – have derived from it.

The Preface to the UN's 2001 report says the intention of its Climate Change Panel is to provide objective information as a basis for decisions by policy-makers. The Introduction adds:

> "Since the release of the Second Assessment Report, additional data from new studies of current and palaeoclimates, improved analysis of data sets, more rigorous evaluation of their quality, and comparisons among data from different sources have led to greater understanding of climate change."

Despite "rigorous evaluation" by the UN, involving not one but two rounds of detailed scrutiny by peer-review, the errors in the key temperature reconstruction graph were not detected; or, if they were detected, they were not corrected.

This defective graph is the only figure which was featured as many as six times in the UN's 2001 report, appearing with great prominence and in full colour on each occasion. The centrality of its importance to the case for alarm may be judged not only from the frequency and prominence of its appearance in the UN's 2001 report but also from the following conclusion, which appears in the *Summary for Policymakers*:

> "New analyses of proxy data for the Northern Hemisphere indicate that the increase in temperature in the 20th century is likely to have been the largest of any century during the past 1,000 years. It is also likely that, in the Northern Hemisphere, the 1990s was the warmest decade and 1998 the warmest year (Figure 1b). Because less data are available, less is known about annual averages prior to 1,000 years before present and for conditions prevailing in most of the Southern Hemisphere prior to 1861."

The UN relied not only upon the flawed Mann *et al.* reconstruction but also upon a series of similar papers contributed to scientific journals, which seemed to support the abolition of the mediaeval warm period, as a report by the House of Lords Economic Affairs Committee (Lords 2005) pointed out.

However, an independent report by statisticians (US Senate 2005), perhaps the most devastating scientific criticism yet leveled at the UN on climate change, concluded not only that the UN's 2001 temperature reconstruction had used inappropriate statistical methods and data but also that many of the supporting scientific papers, both before and after the 2001 report, had been written by a small and closely-connected group of palaeoclimatologists, who effectively dominated their field worldwide, and were all intimately linked to the principal author of the UN's 2001 graph.

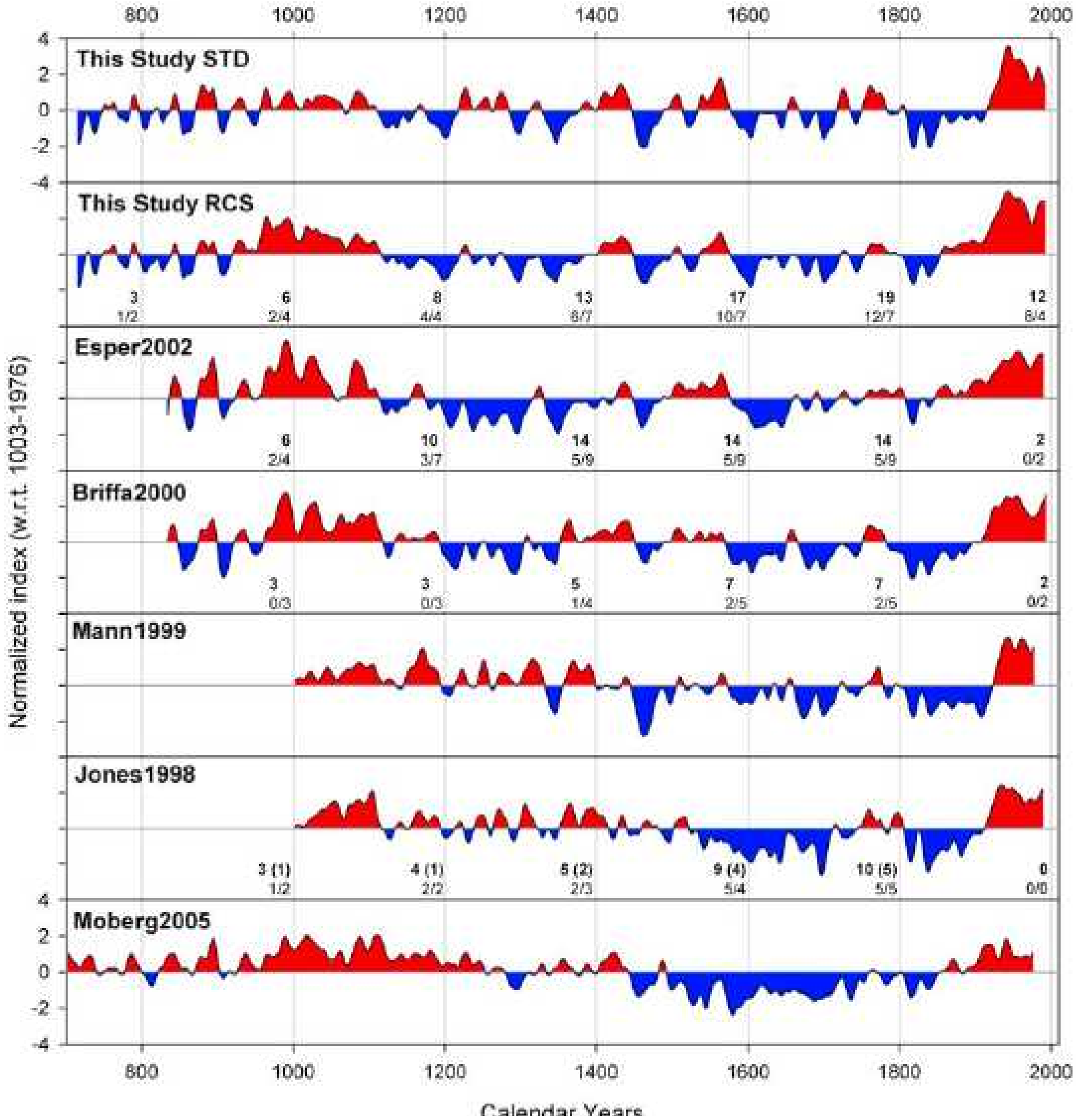
It was not until prolonged pressure had been exerted upon the editors of *Nature* that a (less than complete) corrigendum was published (Mann *et al.,* 2004).

Not only *Nature* but also other leading peer-reviewed scientific journals had refused to publish the first paper by McIntyre *et al.* (2003) exposing the flawed graph. Eventually, *Geophysical Review Letters* (McIntyre *et al.,* 2005) had the courage to break ranks and publish the truth.

The US National Academy of Sciences has since issued a statement that the "hockey-stick" graph was defective. Significantly, however, the UN has issued no statement of apology or correction. It continues to use the "hockey-stick" in its publications.

The Government of Canada circulated a copy of the graph to every household in the nation, together with the alarmist conclusion drawn by the UN. The Canadian Government did not subsequently circulate any correction.

Using comparisons among data from different sources it is possible to answer the questions whether there was a mediaeval warm period, whether it was global and whether it was warmer than the current warm period. US Senate 2005 produced the following graph summarizing the findings of several recent palaeoclimatological studies:



Some historical temperature reconstructions, 750 – 2000 (US Senate, 2005). The mediaeval and current warm periods, and the little ice age, are evident. In three of the studies (Esper, Briffa and Moberg), the mediaeval warm period is shown to have been as warm as, or warmer than, the current warm period.

It is not likely that temperatures sufficiently high to keep SW Greenland sufficiently free of ice to permit widespread cultivation, and to remove much or all of the north polar ice-cap during the summer months, were a purely regional phenomenon.

Soon and Baliunas (2003) reviewed more than 200 proxy studies and concluded that the 20th Century is probably not the warmest or a uniquely extreme climatic period of the last millennium. Their paper was heavily criticized by "consensus" scientists on the ground that the data in several of the studies were not temperature data. Four of the editors of the journal that published the paper resigned in protest at the failure of the peer-review process to prevent publication. Their reaction is in strong contrast with that of the editors of *Nature,* none of whom resigned once they knew that the "hockey-stick" graph which they had published was defective, and of the UN, which failed to publish any correction after the six-times-repeated graph was confirmed to have been defective, and, as noted above, continues to use the defective graph in its publications.

To resolve the controversy, it is insufficient merely to rely upon the fact that the UN's graph was not fit for its purpose. It will be necessary to give an account of several of the independent proxy temperature studies published in recent years. The award-winning, contrarian website of the energetic Idso family of scientists, at www.co2science.org, provides clear and fair summaries of papers relevant to the climate change debate. Their Mediaeval Warm Period database is relevant here.

To balance the considerable northern-hemisphere evidence for the mediaeval warm period, some of which has already been discussed, here are a dozen studies from the southern hemisphere:

SOUTHERN HEMISPHERE TEMPERATURE PROXY STUDIES

Antarctica

Hemer *et al.,* 2003: Changes in the location of the edge of the Amery Ice Shelf were inferred from measurements of biogenic opal, absolute diatom abundance and the abundance of *Fragilariopsis curta* found in sediments retrieved from beneath the ice shelf at a point that is currently 80 km from land's edge. The mediaeval warm period at ca. 750 ^{14}C yr before the present was probably warmer than at any time during the current warm period.

Khim *et al.,* 2002: General climatic features were inferred from a study of the grain size, total organic carbon content, biogenic silica content and, most importantly, magnetic susceptibility of ^{210}Pb- and ^{14}C-dated sediments retrieved from the eastern Bransfield Basin (61°58.9'S, 55°57.4'W) just off the northern tip of the Antarctic Peninsula. Most of the mediaeval warm period (AD 1050-1550) was warmer than the current warm period.

Noon *et al.*, 2003: Primarily summer climatic conditions were inferred from a $\delta^{18}O$ record preserved in authigenic carbonate retrieved from sediments of Sombre Lake (60°43'S, 45°38'W) on Signy Island, maritime Antarctica. The mediaeval warm period (AD 1130-1215) was warmer than the current warm period.

South America

Rein *et al.,* 2005: The authors derived sea surface temperatures from alkenones extracted from a high-resolution marine sediment core retrieved off the coast of Peru (12.05°S, 77.66°W). The results indicated that the warmest temperatures of the past 20,000 years occurred during the late medieval period (AD 800-1250), and that they were about 1.5°C warmer than those of the current warm period.

Thompson *et al.,* 2003: The authors analysed decadally-averaged $\delta^{18}O$ records derived by them and their colleagues from three Andean and three Tibetan ice cores, demonstrating that "on centennial to millennial time scales atmospheric temperature is the principal control on the $\delta^{18}O$ice of the snowfall that sustains these high mountain ice fields," after which they produced "a low latitude $\delta^{18}O$ history for the last millennium" that they use as a surrogate for air temperature. For the Quelccaya Ice Cap (13.93°S, 70.83°W), this work revealed that peak temperatures of the mediaeval warm period were warmer than those of the last few decades of the 20th century.

Mauquoy *et al.,* 2004: Changes in temperature and/or precipitation were inferred from plant macrofossils, pollen, fungal spores, testate amoebae and peat humification in peat monoliths collected from the Valle de Andorra about 10 km to the northeast of Ushuaia, Tierra del Fuego, Argentina (54.75°S, 68.4°W). Evidence for a period of warming-induced drier conditions from 960 – 1020 AD "seems to correspond to the mediaeval warm period (MWP, as defined in the Northern Hemisphere)" and "shows that the mediaeval warm period was possibly synchronous in both hemispheres."

Australasia

Wilson *et al.,* 1979: Temperatures derived from an $^{18}O/^{16}O$ profile through a stalagmite found in a New Zealand cave (40.67°S, 172.43°E) revealed the mediaeval warm period to have occurred between AD 1050 and 1400 and to have been 0.75°C warmer than the current warm period.

Williams *et al.*, 2004: Temperatures were inferred from $\delta^{18}O$ data obtained from four stalagmites found in caves at Waitomo (38.3°S, 175.1°E) on New Zealand's North Island for which 19 TIMS uranium series ages were measured. The mediaeval warm period occurred between AD 1100 and 1400 and was warmer than the current warm period.

Africa

Tyson *et al.,* 2000: Maximum annual air temperatures in the vicinity of Cold Air Cave (24°1'S, 29°11'E) in the Makapansgat Valley of South Africa were inferred from a relationship between colour variations in banded growth-layer laminations of a well-dated stalagmite and the air temperature of a surrounding 49-station climatological network developed over the period 1981 – 1995, as well as from a quasi-decadal-resolution record of oxygen and carbon stable isotopes. The mediaeval warm period (1000 – 1325 AD) was as much as 3-4°C warmer than the current warm period (1961 – 1990 mean).

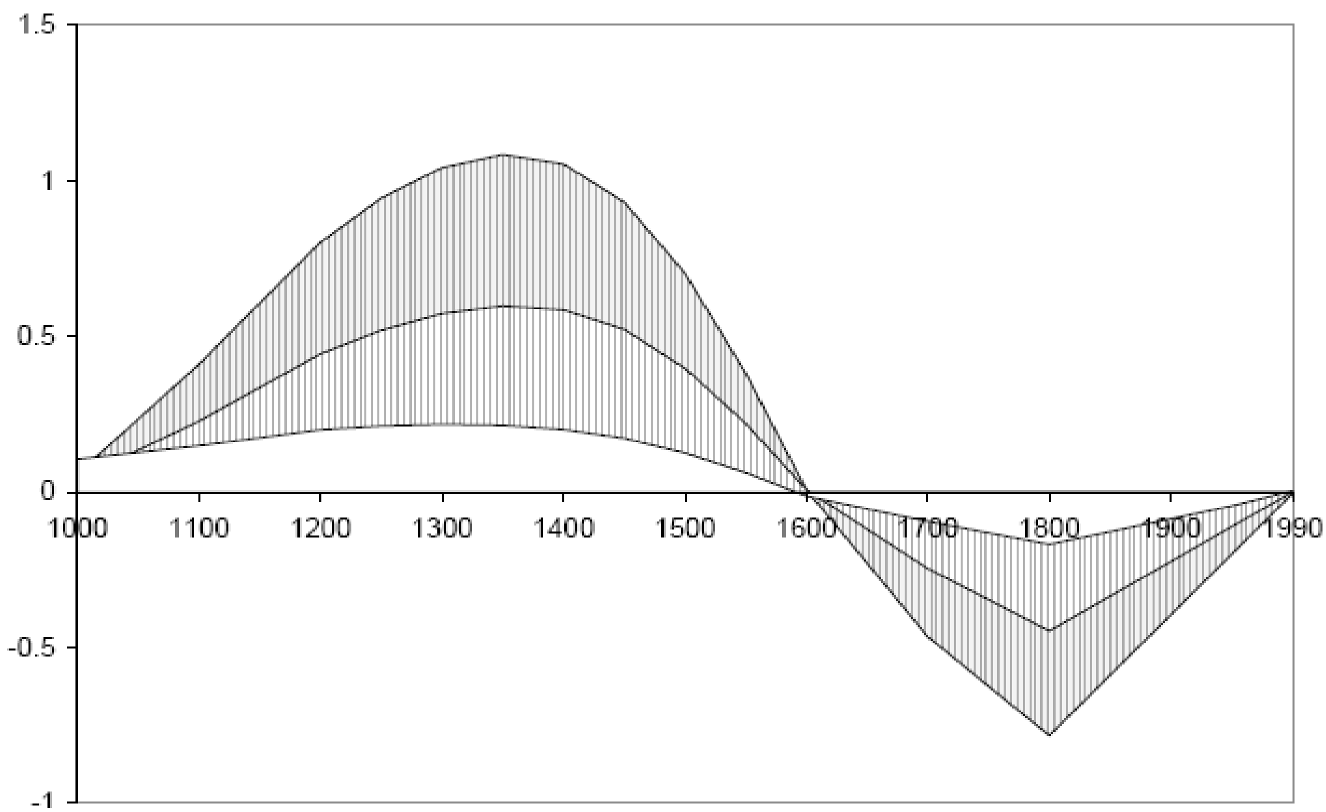
Huffman, 1996: Growing-season moisture and temperature conditions were inferred from the heat and water requirements of the crops (sorghum and millets) known to have been cultivated in southern Africa (centered at approximately 22°S, 29°E), as demonstrated by archaeological investigations. The mediaeval warm period occurred between 900 and 1290 AD and was probably warmer and wetter than the current warm period.

Lamb *et al.*, 2003: The authors present high-resolution pollen data from an 1100-year sediment core taken from Crescent Island Crater Lake (0.75°S, 36.37°E), a sub-basin of Lake Naivasha, in the central Rift Valley of Kenya, which served as a proxy record of changes in the balance between regional precipitation and evaporation. The mediaeval warm period (c.900 – c.1200 AD) was identified as a prolonged period of drought in which the surrounding forest contracted and the lake level dropped. Furthermore, the mediaeval drought was of greater magnitude and duration than recent 20th-century drought.

GLOBAL TEMPERATURE PROXY STUDIES

Several studies, such as Lamb 1965, Grove 1996, 2001, and Ogilvie *et al.* 2001 have suggested that the mediaeval warm period and the little ice age were climatic anomalies on a global scale and not merely regional phenomena.

Shaopeng Huang *et al.* (1995) compiled a major analysis of more than 6,000 ground borehole records from every continent to establish a global proxy temperature record for the past 20,000 years. The reconstruction indicated that the mediaeval warm period was appreciably warmer than the current warm period, which is simply a continuation of the recovery of temperatures following the cold period of the "little ice age" from c.1450 to c. 1750 AD. The portion covering the last millennium is shown here:



Global proxy temperature reconstruction after 1000 AD on ground-borehole evidence, showing average anomalies in degrees C, with Bayesian probability boundaries (Huang et al. 1998; Huang's data) The mediaeval warm period and little ice age are evident.

This diversity of proxy temperature studies from all parts of the world shows that the mediaeval warm period cannot be safely dismissed either as non-existent or as having been confined solely to one region or hemisphere.

Even the theoretical computer models upon which the UN has placed perhaps undue reliance do not always show what the "consensus" scientists might wish them to show. Van Storch *et al.* (2004) challenged the empirical reconstructions of Northern-Hemisphere temperatures, such as that of Mann *et al.* (1998), which demonstrated small-amplitude variations followed by a clear warming trend in the past two centuries. Van Storch used a coupled atmosphere-ocean model simulation of the past 1000 years as a surrogate climate to test the skill of these methods, particularly at multidecadal and centennial timescales. Idealized proxy records were represented by simulated grid-point temperature, degraded with statistical noise. The centennial variability of the Northern Hemisphere temperature was underestimated by the regression-based methods, suggesting that past variations may have been at least double those indicated by empirical reconstructions.

I conclude that today's temperatures are not exceptional, and that the mediaeval warm period was at least as warm as the present and probably up to 3C warmer. However, its timing and extent varied somewhat from place to place, as is to be expected given the mathematically-chaotic nature of climate.

By how much have global temperatures risen since 1900?

The UN's 2001 report asserted that mean global temperatures rose by some 0.6 degrees Celsius between 1900 and 2000. This assertion is derived from 20^{th}-century temperature reconstructions by the Climate Research Unit at the University of East Anglia and the Goddard Institute for Space Studies. However, AccuWeather, a private meteorological corporation, estimates the 20^{th}-century warming at just 0.45C (0.6C to 2006), based on reports from land-based weather stations. The global figure given by the US National Climate Data Center (NCDC 2006) is 5.3C However, in the United States alone, which has had the longest continuous period of reliable temperature measurements, 20^{th}-century temperatures rose by 0.3C (0.4C to 2006), just half the UN's global estimate.

Considering that all these reconstructions of recent global mean temperatures are based on thermometer measurements, it is at first sight surprising that they are all speculative. However, they are indeed subject to the following significant uncertainties:

Urban "heat-island" effects

Most temperature stations are either in cities or in rural areas sufficiently close to cities to be affected by the directly-exothermic industrial activities of humankind. Total anthropogenic heat output is estimated by the US Department of Energy at 44 terawatts, or a mean of 0.09 watts per square metre. Globally, this direct heat output amounts to less than 0.03C: however, the siting of most temperature stations on land either in or close to urban centres has a disproportionate effect on the thermometers from which the global records are calculated. Various methods are used to try to adjust for urban heat-island effects, but it is possible that insufficient allowance has been made.

Early global-warming estimates assumed that urban heating was insignificant because the world's cities – even taken together – only contributed a small amount to total warming. The UN's 2001 report estimates that 0.3C of the past century's 0.6C increase occurred in the most recent 30 years. Many of the climate models upon which the UN forecasts depend assume that cities have only heated by 0.1 degrees Celsius in 30 years and have contributed little to global warming. However, the mean atmospheric temperature in Shanghai, to take one example, has risen by a full 1C in 20 years (Chen, 2003); South Korean cities show similar patterns (Choy, 2003); and the mean night-time temperature in Houston, Texas, rose by 0.7-0.9C in the 12 years 1987-1999 (Streutker, 2003). McKendry (2003) calculated that population-based adjustments for the urban heat island in the United States might be underestimating the urban effect and consequently overstating the increase in the nation's mean atmospheric temperatures. See also Kalnay *et al.* (2002); Rohm *et al.* (1998).

Some climate models now attempt to exclude urban weather stations from their readings. But it is not clear from the technical reports of the UN that sufficient trouble has been taken to exclude reliance by its contributing scientists on population-based and hence frequently misleading temperature data.

Incomplete historical record

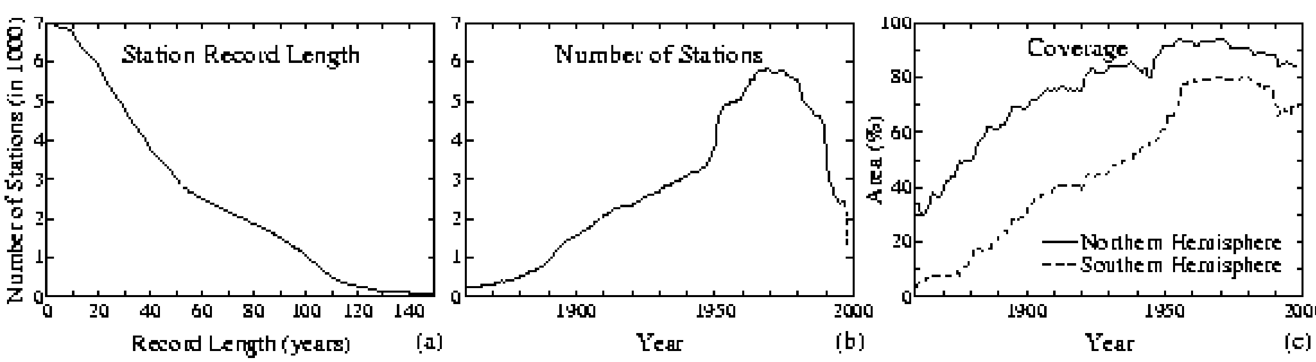
The only reliable records for the first half of the 20th century are from the US. In the UK and other European centres, the ratio of population to land area is too great to allow accurate comparisons; in most other areas, political instability prevents a complete record. Many historically-inaccurate or poorly-correlated records have been used in all reconstructions of 20th-century temperature.

Incomplete geographical spread of temperature recordings

There are very few regular temperature measurements taken at sea, which accounts for 71% of the Earth's surface area. Efforts are now being made to address this problem by the use of inexpensive, disposable sea-temperature sensor buoys. There is also a comparative scarcity of recordings almost everywhere in the Southern Hemisphere. Elaborate and hence uncertain computer modelling is relied upon to interpolate (i.e. guess) temperatures in grid-cells where no records have been taken.

Mass closure of weather stations

The graph of the number of weather stations from which regular and reliable temperature measurements are taken is a startling, reverse "hockey-stick". In the past half-century, the number of weather-stations has fallen from 5,000 to 2,000, only half of which have been keeping records for at least a century. This very rapid decline in weather-stations (centre graph) is disconcerting:



Source: Goddard Institute for Space Studies, NASA

The Antarctic and Greenland / Iceland temperature anomalies

Temperature anomalies persist, and are not easily explained away by the "consensus" theory, which implies that temperatures everywhere will rise. Local climate variability would certainly account for short periods of anomalous temperatures, but some of the anomalies – even on a regional or continental scale - have persisted for at least a third of a century. Such anomalies are not always consistent with the notion that global temperatures are inexorably and rapidly rising and will continue to do so.

Of these temperature anomalies, the most significant in climatic terms are the Antarctic and Greenland/Iceland anomalies. See Sansom (1989) for the Antarctic temperature series, and Petit (1999) for an analysis of ice-core temperature records from the Vostok ice-cores reaching back 420,000 years.

The UN's 2001 report says that about half of any rise in sea levels caused by a warmer climate will come from melting glaciers, the remainder being accounted for by thermal expansion of the oceans. Antarctica contains nine-tenths of the world's ice; Greenland contains another 4 per cent. All other glaciers and ice sheets account for only 6 per cent.

Therefore the climate in Antarctica and, to a lesser extent, in Greenland inevitably dominates discussion of whether ice-melt will cause sea levels to rise.

The snows of Kilimanjaro have been receding. So have the glaciers in Glacier National Park, Washington State, and many other (though not all) mountain glaciers in temperate or equatorial latitudes. However, very nearly all of the world's 160,000+ glaciers (this surprisingly large figure is from the UN's 2001 report) have never been visited by humankind or measured in detail. They are on the high, central plateaux Antarctica and Greenland. The great majority are not melting. They are growing.

Climate models did not at first predict the cooling of the Antarctic ice mass, nor the accumulation of additional mass by precipitation, which always falls as snow on the high Antarctic plateau. It is now thought that the annual disappearance of the stratospheric ozone layer over the Antarctic, within the ambit of the circumpolar circulation, may have been responsible for this local cooling.

The heavy additional precipitation over Iceland and Greenland which has substantially increased the world's ice mass over the past 30 years is now thought to have arisen from the additional moisture in the atmosphere consequent upon warmer global temperatures.

There has been local warming in the Antarctic Peninsula, which accounts for a small fraction of the Antarctic land area, but much of the interior has cooled. Though ice-shelves at the continental periphery have retreated, sea ice has increased (Thompson *et al.,* 2002; Liu *et al.,* 2004), and the trend is increasing (Vyas *et al.,* 2003). The Antarctic sea-ice season is three weeks longer today than in 1979.

Between 1986 and 2000 the valleys of the central Antarctic cooled at a rate of 0.7C per decade, with serious ecosystem damage from cold (Doran *et al.,* 2004). Less ice has melted in the current interglacial period (the Holocene) than during the previous interglacial (Anderson *et al.,* 1999). Side-looking radar interferometry shows that the ice mass in the West Antarctic is growing at a rate estimated at 26.8 gigatons per year, reversing a melting trend that has persisted for 6,000 years (Joughin *et al.,* 2002). There is also evidence for greater ice mass in the East Antarctic (Davis *et al.,* 2005).

"Since 1940, … data have undergone predominantly a cooling trend … The Greenland ice sheet and coastal regions are not following the current global warming trend" (Chylek *et al.* 2004). See also Johannesen *et al.* (2005).

In Iceland, as in Greenland, the first half of the 20th century was warmer than the second half. Most of the Icelandic glaciers receded after 1930 because the summers had warmed, but since 1970 the glaciers have been steadily advancing. They have regained half the ground they had lost. The contrast between growing ice balance on the high plateau and melting at the coastal fringes of Greenland is striking (Krabill *et al.,* 2005)

The anomalously small temperature increases over the past century in Greenland and Antarctica are significant not so much because they do not support the "consensus" theory of universal, global warming as because reconstructions of both temperature and atmospheric concentrations of greenhouse gases now reaching back 900,000 years rely almost exclusively on measurements of air trapped by successive layers of falling snow on the high plateaux of Greenland and Antarctica, where the ice is up to three miles deep.

If temperatures in Antarctica are behaving anomalously now, showing cooling on the high plateau where the ice cores are taken, they may perhaps have behaved anomalously in the past. If so, future palaeoclimatologists examining ice-cores for ^{18}Oxygen isotopes in trapped air as a proxy for temperature would conclude that global temperatures had suddenly fallen in the latter half of the 20th century when we are told that, globally, they rose.

In short, any attempt to reconstruct global temperature histories from ice-cores may be insufficiently reliable to reconstruct interglacial climatic variability correctly on a global rather than a regional scale.

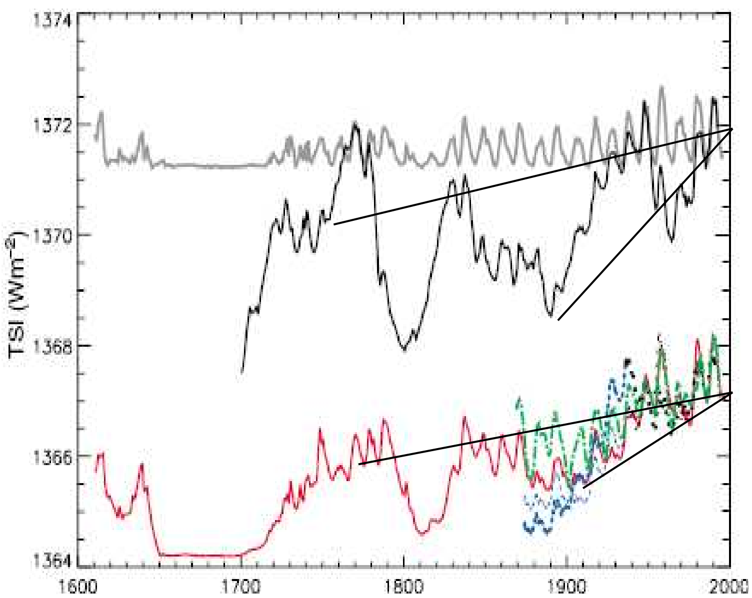
I conclude that the rise in temperatures since 1900 has been far from uniform globally. Overall, temperatures may have risen at only three-quarters of the rate assumed by the UN in its 2001 report. As will be seen later, even a small discrepancy between the UN's assumed 0.6C and the true 20th-century increase in temperature has a significant effect on the calibration of climate-projecting models, and hence on the magnitude of their projections of future climate.

What role has the Sun played in recent warming?

The UN's 2001 report relegated the role of the Sun in causing climate change to a very short sub-chapter. The conclusion was that since 1750 the Sun could not have caused warming amounting to more than 0.3 watts per square metre per second – insufficient to have contributed appreciably to the observed warming of 0.6C between 1900 and 2000. A subsequent study (Hansen, 2006) mentions just 2.2 watts per square metre, but with little discussion. The UN says that solar forcing of climate is less well understood and, accordingly, subject to greater uncertainty than any other forcing. The level of scientific understanding, says the UN is very low.

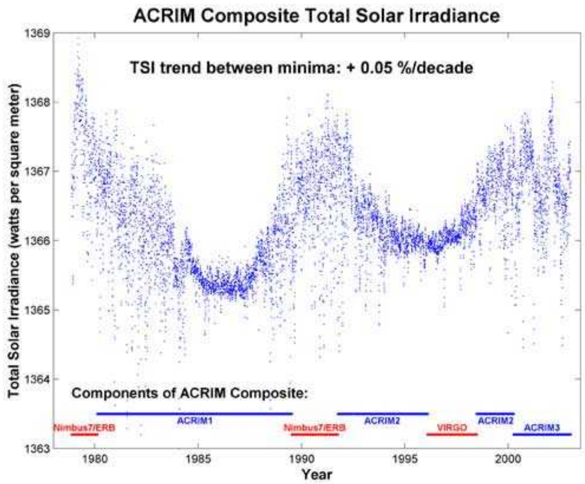
Centennial increases in TSI above the UN's implicit estimate of 1 to 1.75wm^{-2} would imply a correspondingly reduced role for greenhouse gases in 20th-century warming. The UN's central estimate of 0.3wm^{-2} of additional solar forcing at the Earth's surface since 1900 is so small that, in the table of forcings, it merely forms part of a series of little-understood and comparatively insignificant non-greenhouse-gas forcings that broadly cancel each other out.

The UN's estimate of rising temperatures concentrates on the past century: yet its estimates of past forcings, including the radiative forcing from the Sun, date from 1750. The solar forcing from 1750 to the present may be as little as 0.3C, but the solar forcing from 1900 to the present is likely to have been appreciably greater:



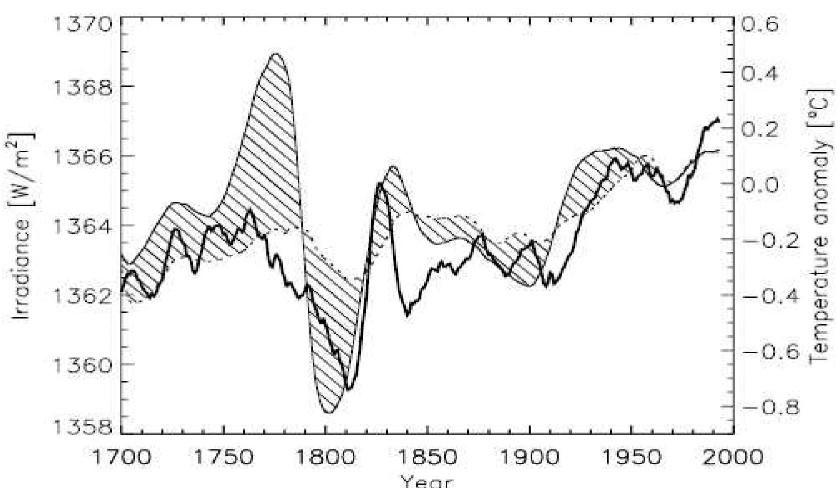
Reconstructions of total solar irradiance (TSI) by Lean et al. (1995, solid red curve), Hoyt and Schatten (1993, data updated by the authors to 1999, solid black curve), Solanki and Fligge (1998, dotted blue curves), and Lockwood and Stamper (1999, heavy dashdot green curve); the grey curve shows group sunspot numbers (Hoyt and Schatten, 1998) scaled to Nimbus-7 observations for 1979 to 1993. Source: UN, 2001. The gradient of the 1900-1998 TSI increase is significantly greater than that of the 1750-1998 increase on which the UN's 2001 report based its solar forcing estimate of 0.3wm^{-2}.

Solanki and Fligge (2003) deduced that in the past half-century the Sun has been hotter, and for longer, than at any time in at least the past 11,400 years. Their work, inevitably relying on proxies for TSI in former times, has recently been extended by Willson (2003), who has concluded that between the last two minima of the 10.6-year solar cycle TSI has risen at a rate equivalent to at least 0.68wm^{-2} per decade:



Reconstructed data from several satellites directly measuring TSI directly over the past quarter-century, correcting for the rapid deterioration of the radiometers and resolving the discrepancies between readings from different satellites (Willson, 2003).

Solanki and Fligge (1999) have shown that reconstructed temperature fluctuations in past centuries, and directly-observed fluctuations in the most recent century, have followed changes in TSI, suggesting a solar contribution to temperature fluctuations:



11-year running mean of two reconstructions of total solar irradiance, including the contribution of both the cyclic and secular components. Thin solid curve: the secular trend is represented by the solar cycle length; thin dashed curve: The amplitude of R_g is used as a proxy of the secular trend. The hatched area between these curves thus gives a rough indication of the uncertainty in the reconstructions. Also plotted is the northern hemisphere land temperature (thick solid curve) according to Groveman and Landsberg (1700 – 1880) and the UN (1880 – 1990). From Solanki and Fligge, 1999.

Between 1900 and 1996, TSI may have risen by as much as $4wm^{-2}$, from 1362 to 1366 wm^{-2}, implying a centennial increase of $0.69wm^{-2}$ at the surface. This is more than twice the $0.30wm^{-2}$ central estimate in the UN's 2001 report.

At the very least, the additional solar radiative forcing effect of some $0.36wm^{-2}$ must be deducted from the total 1900-1998 forcings of $1.98wm^{-2}$, commensurately reducing the greenhouse-gas forcings.

Additionally, climate feedbacks from solar forcing should be considered. Since climate feedbacks from more evaporation and less albedo are temperature-induced and arise as much from solar as from greenhouse-gas forcings, it is not inappropriate to increase total the centennial solar forcing of 0.69 wm^{-2} to take account of the 80% water-vapour and albedo forcings given in Houghton 2002, yielding $1.19wm^{-2}$ of solar-plus-feedback forcing. Deducting the UN's $0.3wm^{-2}$ allowance for direct solar forcing gives $0.89wm^{-2}$ additional solar-plus-feedback forcing, leaving just $1wm^{-2}$ for centennial greenhouse-gas-plus-feedback forcing, of which only $0.55wm^{-2}$ is direct forcing. On this analysis, the Sun may have contributed more than half of the 1900-1998 warming. So low a direct forcing would imply halving the temperature effect of greenhouse-gas forcings. Using the very high forcing-to-temperature conversion factor implicit in the Stern report, the Sun could have caused almost all the increase in temperature observed in the 20th century, allowing no room for any contribution from greenhouse gases. Later in this discussion, when the forcing-to-temperature calculations are considered in more detail, the two model runs which assess the effect of additional solar forcing will assume more conservative estimates than this.

I conclude that the Sun is very likely to have contributed rather more to the past century's warm period than the UN has assumed, and that assumptions about the contribution of greenhouse gases to warming should be revised downward accordingly.

By how much has sea level risen, and by how much will it rise?

Changes in global temperature have historically affected sea levels. Since the end of the last ice age, sea levels have risen steadily as ice has melted from the land and the oceans have undergone thermal expansion. The UN's 2001 report says that in the past century sea levels have risen by between 0.1 and 0.2 metres, and that further warming may accelerate the rise in sea levels, potentially flooding coastal settlements. However, the UN concedes that there is no evidence of any anthropogenic contribution to rises in sea levels so far. See also Baltuck *et al.* (1996), where the same conclusion was reached.

Sea levels have in fact been rising since the last Ice Age drew to its close 12,000 years ago. In that time they have risen by 120 metres – an average of 1 metre per century. Humankind was not the cause. The present rate of sea-level rise, even if the UN's figure is correct, is not a threat.

There has been much concern about whether small, low-lying islands such as the Maldives or Tuvalu will be swamped, but, for geological reasons, nearly all islands that are low-lying are of coral. Corals are more than capable of growing fast enough to match what the UN says is the current rate at which sea levels are rising, and, in the past, have coped with a rate ten times greater.

By 2005, the following islands had exhibited no rise in sea levels at all for the periods shown (Khandekar *et al.,* 2005):

Johnston Island:	**no sea level rise for 50 years**
Tuvalu:	**no sea level rise for 48 years**
Tarawa, Kiribati:	**no sea level rise for 24 years**
Kanton Island:	**no sea level rise for 28 years**
Nauru:	**no sea level rise for 26 years**
Honiara, Solomons:	**no sea level rise for 26 years**
Saipan:	**no sea level rise for 22 years**

Many other records exhibit a stable period followed by a sudden jump, probably caused by hotel or airport construction or by a hurricane, and show no mean temperature increase over the period. The El Nino events of 1983 and 1998 (when global temperature rose very sharply) show abnormally low sea-level readings.

The National Tidal Facility of Australia, which took over the monitoring of sea levels in Tuvalu and the surrouding islands from the University of Hawaii some years ago, and installed state-of-the-art monitoring systems, concludes that over the past decade sea levels in the region may have risen by as much as 5mm per year – about three times the rate mentioned by the UN. However, this may be a regional phenomenon. A tidal benchmark carved in 1888 at Dead Man's Island, New Zealand, is still normally visible even after 120 years.

I conclude that, though sea level is rising, and has been doing so for thousands of years, it is probably not rising at an accelerated rate globally. Given that Greenland is cooler now than in the mediaeval warm period, and given that most of the Antarctic land-mass including almost all the world's 160,000 glaciers has cooled for 30 years, it is not likely that ice-melt will cause considerable rise in sea levels in the foreseeable future. Bearing in mind Lyman (2006), it is also unlikely that thermosteric expansion will cause more than an insignificant rise in sea level in the coming century.

How much will temperature rise in response to CO_2 forcing?

The following paper on the temperature effect of carbon dioxide and other greenhouse gases is not easy for the general reader. It should, however, be accessible to anyone with a working knowledge of elementary climate physics and of simple computer modelling techniques. The paper gives a detailed explanation for the section of the *Sunday Telegraph* article which discusses the arithmetic of the UN and of the Stern Report. The methodological infelicities of the UN are identified and their effect is quantified.

On some analyses, global temperature stopped rising five years ago and will fall this year. However, I have updated the UN's figures assuming a rise of 0.14C between 1998 and 2005. On the basis of new projections calculated by a simple global model, I conclude that temperature in the coming century is not likely to rise by more than 0.6C – about the same rate of increase as in the past century.

Temperature effects of greenhouse-gas forcings

Abstract

THE THIRD Assessment Report of the International Panel on Climate Change (UN, 2001) gives $\lambda = \delta T / \delta E = 0.5$ as the change in mean surface air temperature at the Earth's surface per unit radiant-energy forcing at the tropopause. Hansen (2006) proposes still higher values, $1 \geq \lambda \geq 0.67$, and attributes the shortfall in air temperature change against theory since 1900 to ocean warming. However, use of the Stefan-Boltzmann equation, implying $\lambda \sim 0.3$, yields results that account for the entire radiant-energy increment of the 20th century and are near-identical to those obtained from the UN's CO_2-forcing equation $\delta E = z \ln(C / C_0) \mid z \sim 5.35$. Accordingly the forcing equation, once adjusted for all greenhouse gases, encompasses all forcings and feedbacks. The UN's mention of $\lambda = 0.5$ as a typical value found by the models suggests that the models may be double-counting climate feedbacks. Also, the UN's estimate of 20th-century temperature change may be too high, and – on a growing body of recent evidence – its estimate of solar forcings too low. If so, z, already cut from 6.3 in 1996 to 5.35, remains overvalued. The overvaluation of z as well as of λ, retroactively applied, delivers a 1900-1998 temperature change at least 167% higher than observed. Application of the forcing equation to 2100, with $\lambda \sim 0.3$ and all feedbacks taken as included, shows that the UN has over-projected temperature trends, at the high end by at least a factor of 3. Modelling revises climate sensitivity to a CO_2 doubling from the UN's 1.5-4.5C to **0.7-1.4C.**

THE THIRD ASSESSMENT REPORT of the Intergovernmental Panel on Climate Change (UN 2001) does not refer to the Stefan-Boltzmann equation. Yet this equation is central to answering the key question in the discussion of climate change: how great will be the temperature response to radiant-energy forcings such as elevated greenhouse-gas concentrations? The equation, derived experimentally by Stefan in 1875 and subsequently confirmed theoretically by Boltzmann, gives the total energy flux E integrated over all frequencies or wavelengths as a function of emissivity and temperature:

$$E = \varepsilon \sigma T^4$$

where
- E is radiant energy in watts per square metre per second ($wm^{-2}.s^{-1}$: hereafter "wm^{-2}");
- ε is emissivity, $1 \geq \varepsilon \geq 0$, equivalent by Kirchhoff's Law to absorptivity;
- σ is the Stefan-Boltzmann constant, $5.67 \times 10^{-8} = ac / 4 \mid a$ the radiation constant, c light-speed;
- T is absolute temperature in degrees Kelvin (°C + 273.15).

The UN (2001) briefly discusses the value of $\lambda = \delta T / \delta E$, the equilibrium response of global mean surface air temperature to a change in net tropopausal irradiance (Dickinson, 1982; WMO, 1986; Cess *et al.*, 1993):

> In the one-dimensional radiative/convective models, wherein the concept was first initiated, λ is a nearly invariant parameter (typically, about 0.5K / wm^{-2}; Ramanathan *et al.*, 1985) for a variety of radiative forcings, thus introducing the notion of a possible universality of the relationship between forcing and response. It is this feature which has enabled the radiative forcing to be perceived as a useful tool for obtaining first-order estimates of the relative climate impacts of different imposed radiative perturbations. Although the value of the parameter λ can vary from one model to another, within each model it is found to be remarkably constant for a wide range of radiative perturbations (WMO, 1986). The invariance of λ has made the radiative forcing concept appealing as a convenient measure to estimate the global, annual mean surface temperature response, without taking the recourse to actually run and analyse, say, a three-dimensional atmosphere-ocean general circulation-model (AOGCM) simulation. …

The quoted passage is followed by a lengthy consideration of the "remarkable" invariance of λ, which the general-circulation climate models have treated as though it were an output. However, for the relevant range of climatic temperatures, the Stefan-Boltzmann equation dictates that λ will be a necessarily near-invariant input if the emissivity of the Earth/troposphere system is held constant, as it must be to permit like-for-like comparison of radiative forcings over time.

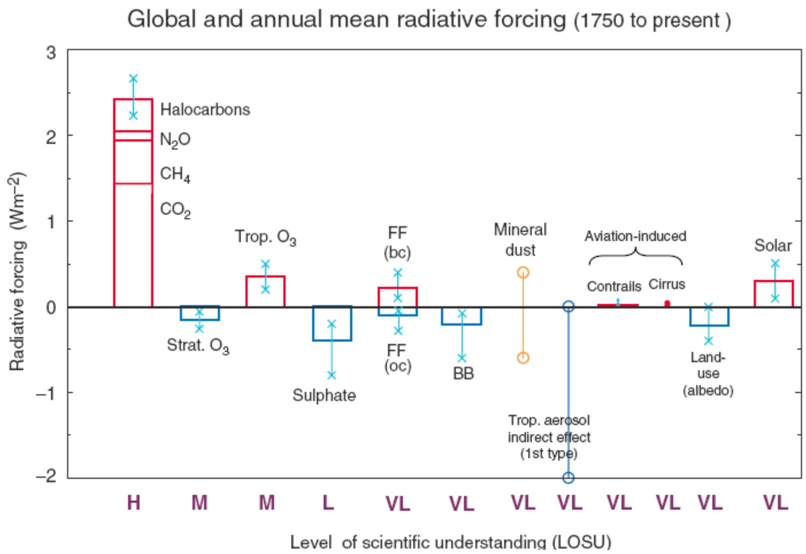
The reason for the near-invariance of **λ** is that over the narrow range of astronomically-low temperatures relevant to climate, the small Stefan-Boltzmann constant offsets the biquadratic T^4, rendering the temperature response to radiative perturbation over that range near-linear. More precisely, with invariant emissivity in the climatic range, **λ** ~ 0.303, diminishing by about 0.001 per wm^{-2} increase in radiant energy. Yet the UN (2001) states **λ** ~ 0.5, in excess of the true value by two-thirds. Some models have used values for **λ** up to 1.0. Houghton (2002) proposes climate feedbacks magnifying direct forcings by 80%, implying **λ** ~ 0.55. He now implies **λ** = 3C / 3.71wm^{-2} = 0.809 (Houghton, 2006). Hansen (2006) cites 0.67, 0.75 and 1.0, two or three times the actual value:

1900-1998	**λ**	**δT**	**Excess δT**	
Base (ε = 1.0000)	0.223			
Actual (ε = 0.6135)	**0.303**	**0.60C**	**0.00C**	**1.00**
UN 1996 (implicit) and 2001:	0.500	0.99C	0.39C	**1.65**
Implicit in Houghton, 2002:	0.545	1.08C	0.48C	**1.80**
Forcings x2 (UN, 2001):	0.606	1.20C	0.60C	**2.00**
Hansen, 2006_1:	0.670	1.33C	0.73C	**2.21**
Hansen, 2006_2:	0.750	1.49C	0.89C	**2.48**
Implicit in Houghton, 2006:	0.809	1.60C	1.00C	**2.67**
Hansen, 2006_3, and GCMs:	1.000	1.98C	1.38C	**3.30**
Implicit in Stern, 2006:	1.890	3.75C	3.15C	**6.25**

The base and actual values of $\lambda = \delta T / \delta E$ *are compared with various estimates of* **λ** *from the UN, from the chairman emeritus of its scientific assessment working group (Houghton, 2002, 2006), from the scientist who first brought climate change to public notice (Hansen, 2006), and from the Stern report (Stern, 2006). Observed temperature over the past century rose in line with the calculated actual value of* **λ,** *but should have risen much further if the various higher values for* **λ** *had been appropriate.*

The UN's temperature projections to 2100 assume that a Clausius-Clapeyron exponential rise in water vapour pressure with temperature causes a climate feedback described as a "near-doubling" of base forcings. In addition, reductions in albedo are thought to amplify base forcings by 20% (Houghton, 2002). Houghton (2006) explains that values **λ** > 0.303 allow for such climate feedbacks. By contrast, Hansen (2006) proposes that the warming of the oceans – in effect a large heat-sink – may explain why observed air temperature rose very uch less in the past century than the elevated values for **λ** would mandate. Using **λ** ~ 0.809 as implied by Houghton (2006), rather than the actual **λ** ~ 0.303, temperatures would have risen between 1990 and 1998 not by the observed 0.5-0.6C but by almost 1.6C – more than two and a half times the observed rate of change. However, calculation using a simple model shows that neither the proposed elevations of **λ** nor the explanation in Hansen (2006) is needed, for there is no discrepancy between observation and the calculated value **λ** ~ 0.303.

The UN (2001) attributes its estimated 1900-1998 increase of 0.6C in temperature chiefly to the forcing effect of rising concentrations of greenhouse gases in the atmosphere: all its other forcings are far smaller, less well-understood, and broadly self-cancelling. The table of forcings between 1750 and 1998 in UN 2001 is shown below:



Calculation shows that the UN's table of historic forcings must include all climate feedbacks. The logarithmic CO_2 forcing equation (UN 1996, 2001) converts increases in CO_2 concentrations to forcings in wm^{-2} thus –

$$\delta E_C = z \ln(C / C_0)$$

Since this equation is a heuristic derived from the climate models, it may appropriately be used for simple, global-mean calculations. To generalize the equation to cover forcings from all greenhouse gases, multiply both sides by ***g,*** the ratio of forcings from all greenhouse gases including CO_2 to the forcing from CO_2 alone, noting in passing that ***g*** is not a constant: the UN (2001) expects its value, ***g*** = 1.664 in 1998, to fall to ~1.250 by 2100. The all-gases forcing equation is –

$$\delta E_{ghg} = g.\delta E_C = gz \ln(C / C_0)$$

The UN (1996) had given ***z*** = 6.3, but cut ***z*** to 5.35 by 2001. Taking C_0 = 278ppmv in 1750 and ***C*** = 365ppmv in 1998, the UN's forcing equation, in agreement with its table below, gives a radiative forcing from CO_2 of 1.46 wm^{-2} plus 0.97wm^{-2} for the sum of the forcings from all other greenhouse gases, for a total forcing of 2.43 wm^{-2}:

Gas	Abundance (Year 1750)	Abundance (Year 1998)	Radiative forcing (Wm^{-2})
Gases relevant to radiative forcing only			
CO_2	278	365	1.46
CH_4	700	1745	0.48
N_2O	270	314	0.15
CF_4	40	80	0.003
C_2F_6	0	3	0.001
SF_6	0	4.2	0.002
HFC-23	0	14	0.002
HFC-134a	0	7.5	0.001
HFC-152a	0	0.5	0.000
Gases relevant to radiative forcing and ozone depletion			
CFC-11	0	268	0.07
CFC-12	0	533	0.17
CFC-13	0	4	0.001
CFC-113	0	84	0.03
CFC-114	0	15	0.005
CFC-115	0	7	0.001
CCl_4	0	102	0.01
CH_3CCl_3	0	69	0.004
HCFC-22	0	132	0.03
HCFC-141b	0	10	0.001
HCFC-142b	0	11	0.002
Halon-1211	0	3.8	0.001
Halon-1301	0	2.5	0.001

To find the proportion of the listed 1750-1998 forcings which arose between 1900 and 1998, mean CO_2 concentrations of 292ppmv in 1900 (UN, 2001) rose by exactly 25% to 365ppmv in 1998 (Mauna Loa annual mean). The UN's CO_2 forcing equation yields the centennial forcing thus: $\boldsymbol{\delta E_C}$ = 5.35 ln(365 / 292) = 1.19 wm^{-2}. The table implies that in 1998 the ratio $\boldsymbol{g}$ of forcings from concentrations of all greenhouse gases to the forcing from CO_2 alone was 2.43 / 1.46 = 1.664. Then the all-greenhouse-gas forcings equation yields the total forcing between 1900 and 1998 using the UN's method: $\boldsymbol{\delta E} = \boldsymbol{g.\delta E_C}$ = 1.19 x 1.664 = **1.99 wm^{-2}.**

This centennial forcing $\boldsymbol{\delta E}$ from all sources can also be directly computed from the Stefan-Boltzmann equation. With emissivity 0.6134 at 14.3C, tropospheric radiant-energy flux is 237.50wm^{-2}. Deducting 235.52wm^{-2} for the energy flux in 1900 gives the centennial forcing of **1.98wm^{-2},** a near-identical result.

The observed 0.6C temperature change used in the Stefan-Boltzmann calculation includes climate feedbacks by definition, because, over as long a period as a century, any appreciable climate feedbacks will have added their contribution to that temperature change. Since the UN's all-greenhouse-gas forcing equation gives a result identical to that calculated by reference to observed centennial temperature increase $\boldsymbol{\delta T}$**,** it must also incorporate the forcing effect of all climate feedbacks, unless it is assumed that the oceans or some other agency are masking additional temperature**.** Subject to this, the UN's table of forcings and its forcing equation are thus demonstrated to be inclusive of all feedbacks. Likewise $\boldsymbol{\lambda} \sim 0.303$, implicit in the Stefan-Boltzmann equation, is shown to require no further adjustment to take account of climate feedbacks over the century 1900-1998.

To update the calculation to 2006, temperature has risen by ~ 0.14C since 1998, equivalent to 0.46wm^{-2}, and CO_2 concentration rose from 365 to 380ppmv. Forcings rose by 5.35$\boldsymbol{g}$ ln(380 / 365) = 0.35wm^{-2}, or 0.11wm^{-2} below observation. However, between the 1998 solar minimum and the 2004 maximum, TSI rose by ~1.1wm^{-2} (Willson, 2003), equivalent to 0.19wm^{-2} at the surface. Therefore no additional allowance for climate feedbacks is necessary to account for the 1998-2006 temperature change. The astronomer William Herschel noted an inverse correlation between sunspot numbers and the price of grain (Hufbauer, 1991), demonstrating that the 10.6-year solar cycles have a detectable effect on temperature and hence on crop growth-rates. Since temperature responds detectably and intra-decadally to surface-energy-flux changes $\boldsymbol{\delta E}$ < 0.2wm^{-2}, it is very unlikely that as much as 1C of additional warming would have failed to manifest itself intra-centennially as posited by Hansen (2006).

The UN's 0.6C of observed warming between 1900 and 1998 is at the high end of the range of available estimates. Compariing 5-year means, the US National Climate Data Center (NCDC 2006) gives 0.53C. AccuWeather, based on land stations only, gives 0.45C. Adopting a lesser value than the UN's 0.6C would further increase the discrepancy between the observed temperature increase since 1900 and the higher values resultant from the UN's methods of projection. If the lower centennial temperature increase estimated by NCDC were applied, it would be legitimate to infer that the all-greenhouse-gases forcing equation, $\boldsymbol{\delta E = gz \ln(C/C_0)}$, itself produces overstated forcings, and that $\boldsymbol{z}$ should be further cut from the UN's current value of 5.35 to 4.71.

The UN may have underestimated the role of the Sun, on which there is a growing literature. Centennial increases in solar surface-energy flux above UN 2001's central estimate of 0.30wm^{-2} since 1750 would demand yet further reductions in $\boldsymbol{z}$**.** The UN's solar-forcing estimate is so small that, in the forcings table, it is one of various minor, self-cancelling forcings. Though the UN's 0.6C estimate of rising temperature has 1900 as its base year, its estimate of solar forcings, takes 1750 as the base year. Solar forcing from 1750 to the present may have been only 0.3C, but the solar forcing from 1900 to the present was much greater: in 1750 the Sun was significantly warmer than in 1900 and ended the "little Ice Age" (Lean *et al.,* 1995; Hoyt & Schatten, 1993; Solanki & Fligge, 1998).

Solanki *et al.* (2005) deduced that in the past half-century the Sun has been hotter, and for longer, than at any time in at least the past 11,400 years, directly accounting, before climate feedbacks, for perhaps a quarter of the past century's warming. Willson (2003) has recently concluded from satellite observations that between the last two minima of the 10.6-year solar cycle TSI has risen at a rate equivalent to ~ $0.68 wm^{-2}$ per decade. If this rate of change had persisted throughout the last century, the direct forcing from the Sun at the Earth's surface would have been $1.17\ wm^{-2}$. When temperature-induced climate feedbacks arise, they do so as much from solar as from greenhouse-gas forcings. Therefore, multiplying 1.17 by 2.67 (Houghton, 2006) for climate feedbacks would yield $3.04 wm^{-2}$ after climate feedbacks – more than one and a half times the observed warming of $1.98 wm^{-2}$.

However, solar activity declined a little in the 25 years between 1945 and 1970, followed closely by temperature, while CO_2 concentrations, by contrast, monotonically rose. Accordingly the upper bound of the solar-plus-feedbacks contribution to the past century's warming is perhaps ~$1.50\ wm^{-2}$ at the surface, or ~71% of observed warming (*cf.* Soon *et al.*, 1993). Deducting the UN's $0.30\ wm^{-2}$ allowance for solar forcing (already cancelled by minor, negative forcings in the UN's table) gives $1.2\ wm^{-2}$ additional solar forcing, leaving only $0.79\ wm^{-2}$ for centennial greenhouse-gas forcing and requiring the coefficient z to be cut by more than half. However, in the solar-forcing scenarios M3 and M4 below, a cautious $1.00 wm^{-2}$ solar forcing between 1900 and 1998 is assumed.

More recently, Svensmark *et al.* (2006) have described an additional solar forcing. Higher TSI occurs in parallel with amplification of the Sun's magnetic field, which reduces the flux of cosmic rays that stimulate cloud formation in the atmosphere. The resultant reduction in cloudiness, especially low-altitude clouds which have a net cooling effect, may have contributed significantly to the past century's warming, commensurately reducing the contribution from greenhouse-gas and like forcings. This additional solar forcing is not quantified here.

This comparison of the UN's methods with physical laws as applied to the past century establishes baseline data for input into a simple climate model to compare UN 2001's projections for future climate change with new projections. The UN used a simple model to create projections from the atmosphere-ocean general-circulation climate models upon which its 2001 report relied. Also, the UN states in the quoted passage that the invariance of λ makes its radiative-forcing concept "a convenient measure to estimate the global annual mean surface temperature response" without recourse to complex models. For these reasons, a simple model to derive globally-averaged projections from the Stefan-Boltzmann equation and the UN's forcings heuristic is sufficiently skilful.

Four scenarios were compared against the UN's minimum and maximum projections of temperature increase to 2100 and of climate sensitivity to a doubling of atmospheric CO_2 concentrations –

> **Scenario M1: Base scenario:** On this scenario, calculations to 1998 were near-identical to those using the UN's distinct method, demonstrating that neither λ nor z should be elevated to account for climate feedbacks.
>
> **Scenario M2: 20^th^-century temperature increase 0.53C:** The 1900-1998 temperature increase was taken as 0.53C (NCDC) instead of 0.6C (UN, 2001), with commensurate reduction of the forcing coefficient z.
>
> **Scenario M3: Greater solar forcing:** 1900-1998 top-of-atmosphere TSI increase was taken not as $1 wm^{-2}$ but as $2.50\ wm^{-2}$, (*cf.* ~$4 wm^{-2}$ in Hoyt & Schatten, 1993, updated to 1999 by the authors and cited in UN, 2001).
>
> **Scenario M4: M1+M2+M3:** 1900-1998 temperature increase was taken as 0.53C (NCDC), with TSI increase $2.50 wm^{-2}$, and commensurate reduction of the forcing coefficient z.

In each scenario, three cases were evaluated: the UN's low-end and high-end projections for CO_2 concentrations in the atmosphere by 2100, and its "climate-sensitivity" parameter – a theoretical doubling of CO_2 concentrations:

Case A is UN 2001's low-end projected CO_2 concentration increase of **540ppmv** by 2100. Since recording of CO_2 concentrations began in 1958, concentrations have risen at 0.38% per year compound. If this rate continues to 2100, concentrations will be 541ppmv. Many of the UN's models calculate their scenarios by assuming that CO_2 will rise at 1%pa – almost three times the observed rate over the past half-century. This is the most likely case.

Case B doubles CO_2 from 381ppmv in 2006 to **760ppmv.** It is not likely that CO_2 concentrations will double by 2100. The UN uses a doubling of CO_2 concentrations as what it calls its "climate-sensitivity" parameter.

Case C is UN 2001's high-end (but very unlikely) CO_2 increase of **970ppmv** by 2100, which depends on the assumption that population will rise to 15 billion by 2100. Most demographers assume a peak of 10bn by 2050, followed by a sharp fall.

Results were –

Projected changes in mean surface air temperature, 2006 to 2100

M4 **M3+M2+M1**	**M3** **$2.5 wm^{-2}$ solar**	**M2** **+0.53C to 1998**	**M1** **Base scenario**	Case	***UN*** ***T.A.R. 2001***
+ 0.07 C	**+ 0.15 C**	**+ 0.53 C**	**+ 0.61 C**	A : 540ppmv by 2100	**+ *1.4 C***
+ 0.73 C	**+ 0.90 C**	**+ 1.22 C**	**+ 1.38 C**	B : 760ppmv = 2x CO_2	**+ *1.5 to 4.5 C***
+ 0.69 C	**+ 0.91C**	**+ 1.56 C**	**+ 1.78 C**	C : 970ppmv by 2100	**+ *5.8 C***

At no point does the projected range of temperature increases overlap with the exotically higher range proposed in UN 2001. The modest further warming that is projected would be very unlikely to trigger climate feedbacks above those inherent in the UN's forcings-equation and, as discussed, incorporated fully into the model. Such small increases fall comfortably within millennial variability, especially in the light of many proxy temperature studies, from both hemispheres and using different methodologies, indicating that the mediaeval climate optimum may have been warmer than the current warm period by up to 3C (e.g. Bond *et al.,* 2001; Haberzettl *et al.,* 2005; Hu *et al.,* 2001; Huang and Pollack, 1997; Martinez-Cortizas *et al.,* 1999; Polissar *et al.,* 2006).

The modest warming projected here would not be likely to instigate major climatic phase transitions or abrupt climate change, which are in any event chaotic in the mathematical sense and hence unpredictable by definition. In all cases, and on all scenarios, the UN's methods are shown to have induced very large overstatement in all the key temperature projections, at the high end by at least a factor of three.

APPENDIX A Initial state of the M climate model

Temperature *T* in 2006 is taken as ~14.4C = 287.55K. Temperatures for other years are anomalies from this base value (precise evaluation of absolute air temperature is problematic, but few errors arise from any reasonable base value). Temperature in 1900, the base year for calculations here, is taken as ~13.7C; in 1998, 14.3C, a rise of 0.6C.

The correct value of λ is implicit in the Stefan-Boltzmann equation, which was used in all scenarios.

Top-of-atmosphere TSI was 1366wm^{-2} in 1998 (Willson, 2003), falling to its 1900 level by 2100 (Schatten and Tobiska, 2003; Landscheidt, 2003).

Mean tropospheric CO_2 concentration in 1750 was 278ppmv; in 1900, 292; in 1998, 356; in 2006, 380.

The all-greenhouse-gases coefficient *g* = 1.664 at 1998, falling to 1.632 in 2006 and 1.250 by 2100 (UN 2001).

Solar forcing: UN 2001 gives 0.30wm^{-2} for 1750-1998 solar forcing – base forcing 0.11wm^{-2} and climate feedbacks 0.19wm^{-2} or 167% of the base forcing (implicit in Houghton, 2006). In scenarios M1-M2, 1900-1998 solar forcing was taken as identical to 1750-1998, implying top-of-atmosphere TSI in 1900 at 1365.35wm^{-2}, 0.65wm^{-2} below the satellite-observed 1366wm^{-2} at the 1998 solar minimum (Willson, 2003). Since a disc has a quarter the area of a sphere's surface, surface energy flux ***E*** is a quarter of top-of-atmosphere TSI.

Albedo α = 0.31 reflects almost a third of solar irradiance to space, reducing ***E*** accordingly, so that the surface temperature of the Earth as a blackbody of emissivity 1 would have been –19.3C.

Natural greenhouse effect: Temperature in 1900 was 13.7C, implying a "greenhouse effect" of 33C, equivalent to 148wm^{-2} (*cf.* 20-30C and 146wm^{-2} in Houghton, 2002). Since anthropogenic enhancement of the greenhouse effect was negligible in 1900, nearly all of the 33C is the natural greenhouse effect.

Earth-troposphere emissivity: With ***E*** = 235.52wm^{-2} (*cf.* 236wm^{-2} in Houghton, 2002) at 13.7C, the Stefan-Boltzmann equation gives ε ~0.6135 in 1900, pegged to allow like-for-like comparison of forcings over time.

APPENDIX B Calculations from 1900 to 1998

M CLIMATE MODEL	*Initialize & calibrate*	*Scenario M1*	*Scenario M2*	*Scenario M3*	*Scenario M4*
No.: Item	**Method of calculation**	**Boltzmann**	**M1+δT=0.53C**	**M1+Solar**	**M1+M2+M3**
01: δE solar (base+fb)	Input	0.30wm^{-2}	0.30wm^{-2}	1.00wm^{-2}	1.00wm^{-2}
02: TSI 1900	Input	135.35wm^{-2}	1365.35wm^{-2}	1363.83wm^{-2}	1363.83wm^{-2}
05: *T* 1900	Input	13.70C	13.77C	13.70C	13.77C
06: *T* 1998	Input	14.30C	14.30C	14.30C	14.30C
07: *T* 2006	Input	14.44C	14.44C	14.44C	14.44C
08: *E* 1900	**v01**$(1-\alpha)/4$	235.52wm^{-2}	235.52wm^{-2}	235.26wm^{-2}	235.26wm^{-2}
cf. Houghton, 2002	*Input*	*236.00wm^{-2}*			
09: *T* blackbody	(**v08** / $\sigma)^{1/4}$ – 273.15	– 19.28C	– 19.28C	– 19.35C	– 19.35C
10: *T* nat.gh effect	**v05 – v09**	+ 32.98C	+ 33.05C	+ 33.05C	+ 33.12C
11: ε emissivity	**v08** / [σ(**v05** + 273.15)^4]	0.6135	0.6129	0.6128	0.6122

12: ***E*** 1998	**(v11)** σ (**v06** + 273.15)^4	237.50wm^{-2}	237.27wm^{-2}	237.24wm^{-2}	237.00wm^{-2}
13: $\boldsymbol{\delta E}$ 1900-1998	**v12** – **v08**	1.98wm^{-2}	1.75wm^{-2}	1.97wm^{-2}	1.74wm^{-2}
14: $\boldsymbol{\delta E}$ solar before FB	(**v02** – **v01**)(1 – α) / 4	0.11wm^{-2}	0.11wm^{-2}	0.37wm^{-2}	0.37wm^{-2}
15: Solar feedbacks	0.8(**v14**)	0.19wm^{-2}	0.19wm^{-2}	0.63wm^{-2}	0.63wm^{-2}
16: Solar increment	**v14** + **v15** – 0.30	0.00wm^{-2}	0.00wm^{-2}	0.70wm^{-2}	0.70wm^{-2}
17: $\boldsymbol{\delta E_{ghg}}$ forcing	**v13** – **v16**	1.98wm^{-2}	1.75wm^{-2}	1.27wm^{-2}	1.04wm^{-2}
cf. *UN equation*	*5.35[1.664 ln(365 / 292)]*	***1.99wm^{-2}***			
25: $\boldsymbol{z}$ forcing coefficient	**v17** / [1.664 ln(365 / 292)]	5.32	4.70	3.43	2.81
cf. *UN coefficient*		***5.35***			

To this point, no reference to CO_2 has been necessary to derive the total forcings shown at line 17 of scenario M1. The UN's all-greenhouse-gases forcing equation, shown for comparison, produces a near-identical result.

Since observed temperature increases must by definition include climate feedbacks from forcings, the UN's table of forcings to 1998 is shown to include such feedbacks, implying that the UN's new central value $\boldsymbol{\lambda = \delta T / \delta E}$ = 3C / 3.71wm^{-2} ~ 0.809 (implicit in Houghton, 2006) effectively double-counts climate feedbacks.

Accordingly it would be incorrect to make additional provision for feedbacks, or to give $\boldsymbol{\lambda = \delta T / \delta E}$ any value greater than that implicit in the Stefan-Boltzmann equation.

In line 25 the forcing coefficient $\boldsymbol{z}$ is calculated, and, in scenario M1, is very close to that given in UN 2001. In scenarios M2 to M4, $\boldsymbol{z}$ is lower than in M1, reflecting the diminished 1990-1998 warming role of greenhouse gases if temperatures did not rise as fast as the UN's 0.6C (M2) or if the sun caused more warming than the UN's 0.30wm^{-2} (M3), or both (M4). UN 1996 valued $\boldsymbol{z}$ at 6.3.

Though UN 2001 cut **z** to 5.35 but left $\boldsymbol{\lambda}$ ~ 0.5 as in 1996, its range of projected temperature increases for doubling CO_2 rose from 1.0-3.5C, central estimate 2.5C, in 1996 to 1.5-4.5C, central estimate 3C, in 2001.

APPENDIX C Calculations updated to 2006

M **CLIMATE MODEL**	*Update to 2006*	*Scenario M1*	*Scenario M2*	*Scenario M3*	*Scenario M4*
No.: Item	**Method of calculation**	**Boltzmann**	**M1+$\boldsymbol{\delta}$T=0.53C**	**M1+Solar**	**M1+M2+M3**
26: ***E*** 2006	**(v11)** σ (**v07** + 273.15)^4	237.96wm^{-2}	237.73wm^{-2}	237.70wm^{-2}	237.47wm^{-2}
27: $\boldsymbol{\delta E}$ 1998-2006	**v26** – **v12**	0.46wm^{-2}	0.46wm^{-2}	0.46wm^{-2}	0.46wm^{-2}
28: $\boldsymbol{\delta E_{ghg}}$ forcing	**(v25)(v23)** ln(**v20** / **v19**)	0.35wm^{-2}	0.31wm^{-2}	0.23wm^{-2}	0.18wm^{-2}
29: $\boldsymbol{\delta E + \phi}$ solar forcing	**v27** – **v28**	0.11wm^{-2}	0.15wm^{-2}	0.24wm^{-2}	0.28wm^{-2}
30: $\boldsymbol{\delta E}$ solar - feedbacks	**v29** / 1.8	0.04wm^{-2}	0.06wm^{-2}	0.09wm^{-2}	0.10wm^{-2}
31: $\boldsymbol{\delta I}$ δTSI 1998-2006	4(**v30**) / (1 – α)	0.25wm^{-2}	0.33wm^{-2}	0.51wm^{-2}	0.60wm^{-2}
cf. *UN 2001*	*% cycle min.-max. 1.1wm^{-2}*	*22.33%*	*30.33%*	*46.76%*	*54.76%*

First the energy-flux in 2006 is found. Using the forcing coefficient in line 25, the greenhouse-gas contribution to the increase in energy flux between 1998 and 2006 is calculated and subtracted from the energy-flux to calculate the solar contribution. Solar feedbacks are allowed for, and, finally the implied TSI increase is found.

In every scenario the implied TSI increase is considerably lower than the UN's value for the observed increase of ~1.1wm-2 between solar minima (such as that in 1998) and maxima (such as 2004). These calculations establish baseline data and calibration for the projections which follow.

APPENDIX D Projections to 2100

Case A: CO_2 rises to 540ppmv in 2100 (UN "business-as-usual" case)

M CLIMATE MODEL No.: Item	*CO_2 at 540ppmv* **Method of calculation**	*Scenario M1* **Boltzmann**	*Scenario M2* **M1+δT=0.53C**	*Scenario M3* **M1+Solar**	*Scenario M4* **M1+M2+M3**
33: δE_{ghg} 2006-2100	(**v25**)[1.25 ln(540 / **v20**)]	2.34wm^{-2}	2.06wm^{-2}	1.78wm^{-2}	1.51wm^{-2}
34: δE_{sun} 2006-2100	– **v1**	– 0.30wm^{-2}	– 0.30wm^{-2}	– 1.00wm^{-2}	– 1.00wm^{-2}
35: E 2100	**v26** + **v33** + **v34**	240.00wm^{-2}	239.49wm^{-2}	238.21wm^{-2}	237.70wm^{-2}
36: T 2100	[**v35** / (**v11**) / σ]$^{1/4}$– 273.15	15.05C	14.97C	14.59C	14.51C
37: δT 2006-2100	**a36** – **v07**	+ 0.61C	+ 0.53C	+ 0.15C	+ 0.07C

In 1958, when atmospheric CO_2 was first measured at Mauna Loa, the concentration was 316ppmv, rising to 380ppmv in the 48 years to 2006, an annual increase of 0.38%. Assuming the same rate to 2100, the CO_2 concentration would be 543ppmv (cf. 540ppmv given in UN 2001).

Accordingly, the UN's "business-as-usual" projection assumes no worldwide measures to reduce emissions, and no increase in the rate of growth in CO_2 concentrations observed since 1958.

On scenario M1, which removes the double-counting of climate feedbacks in UN 2001, temperature is forecast to rise by little more than 0.6C, a similar rate to that which was observed in the past century. On scenarios M3 and M4, more solar influence is assumed for the past century than UN 2001 allowed. Correspondingly less greenhouse-gas influence is assumed. Also, a decline in solar activity from its 2005 peak to its estimated 1900 level is assumed for 2100.

If just 0.5wm^{-2} of TSI less than the 1900 value taken in scenarios M3-M4 were assumed, elevating the solar contribution to the last century's warming a little further, temperature would not change at all between now and 2100. Scenario M4, combining the effects of the previous three scenarios, shows a temperature increase of less than 0.1C to 2100.

Climate effects of increases as small as these would be negligible. Even the highest of these values is well below half of UN 2001's minimum projection of a 1.4C temperature increase to 2100.

Case B: CO_2 doubles to 760ppmv (UN "climate-sensitivity" case)

M CLIMATE MODEL No.: Item	*CO_2 doubles to 760ppmv* **Method of calculation**	*Scenario M1* **Boltzmann**	*Scenario M2* **M1+δT=0.53C**	*Scenario M3* **M1+Solar**	*Scenario M4* **M1+M2+M3**
38: δE_{ghg} 2006-2xCO_2	(**v25**)[1.25 ln(760 / **v20**)]	4.61wm^{-2}	4.07wm^{-2}	2.97wm^{-2}	2.43wm^{-2}
39: δE_{sun} 2006-2xCO_2	– **v1**	– 0.30wm^{-2}	– 0.30wm^{-2}	– 1.00wm^{-2}	– 1.00wm^{-2}
40: E 2xCO_2	**v26** + **v38** + **v39**	242.58wm^{-2}	241.80wm^{-2}	240.67wm^{-2}	239.90wm^{-2}
41: T 2xCO_2	[**v40** / (**v11**) / σ]$^{1/4}$– 273.15	15.82C	15.66C	15.34C	15.17C
42: δT 2006-2xCO_2	**a41** – **v07**	+ 1.38C	+ 1.22C	+ 0.90C	+ 0.73C

For comparison of climate sensitivities, no fall in TSI to 2100 is assumed in Case B. UN 2001 estimates a temperature rise of 1.5 to 4.5C for a doubling of CO_2. Doubling is not likely to occur by 2100, but the UN uses doubling as its "climate-sensitivity" case. The present model, removing the UN's apparent double-counting of feedbacks, suggests a range of +0.7 to +1.4C. The entire range is below the UN's lowest estimate of climate sensitivity.

Case C: CO_2 rises to 970ppmv by 2100 (UN "15bn population" case)

M CLIMATE MODEL **No.: Item**	*CO_2 at 970ppmv* **Method of calculation**	*Scenario M1* **Boltzmann**	*Scenario M2* **M1+δT=0.53C**	*Scenario M3* **M1+Solar**	*Scenario M4* **M1+M2+M3**
43: δE_{ghg} 2006-2100	(**v25**)[1.25 ln(970 / **v20**)]	6.24wm^{-2}	5.51wm^{-2}	4.02wm^{-2}	3.29wm^{-2}
44: δE_{sun} 2006-2100	– **v1**	– 0.30wm^{-2}	– 0.30wm^{-2}	– 1.00wm^{-2}	– 1.00wm^{-2}
45: E 2100	**v26** + **v43** + **v44**	243.90wm^{-2}	242.94wm^{-2}	240.72wm^{-2}	239.76wm^{-2}
46: T 2100	[**v45** / (**v11**) / σ]$^{1/4}$– 273.15	16.22C	16.00C	15.35C	15.13C
47: δT 2006-2100	**a46** – **v07**	+ 1.78C	+ 1.56C	+ 0.91C	+ 0.69C

Here UN 2001 assumes that world population will rise to 15 billion by 2100. Most serious demographic projections are that world population will peak at ~10bn in 2050, declining rapidly thereafter. In scenario M4, the projected temperature effect is less than in Case B because in Case B no deduction is made for a projected fall in TSI between 2006 and 2100. Even in the very unlikely case that population reaches 15bn, this model suggests temperature might rise by 0.7 to 1.8C by 2100. UN's estimate of 5.8C is more than three times the upper and more than eight times the lower value calculated here.

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