From the Chief Scientific Adviser to HM Government
and Head of the Government Office for Science
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Lord Lawson of Blaby
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Dear Nigel

As promised in my letter of 15th June, I now respond in some detail to your letter of 25th May. My apologies for the delay in responding, but as you will understand it has been a busy time.

I now turn to the specific points you raise:

You claim that the recorded temperature standstill so far this century does not undermine the AGW theory. Maybe; but it certainly does not support it. The essence of your point seems to be the assumption that, while the temperature record over 20 years (from 1980 to 2000) is immensely significant, the temperature record over 10 years (the first decade of the 21st century) is of no significance at all. I know of no scientific basis for this seemingly arbitrary distinction. While I accept that 10 years' evidence should be given less weight than 20 years' evidence, the difference is surely merely one of degree, and indeed even 25 years must be inconclusive. Most climate scientists when pressed, accept that the sources of natural temperature variability have scales which probably run up to centuries, which makes attribution impossible unless the models accurately portray this variability, which they do not.

Firstly, I should say that your representation of my argument does not accurately reflect what I wrote. The point I was making is that in order to assess the impact of greenhouse gases on global temperature, it is necessary to consider the long-term (multi-decadal) trend because natural, internal variations in the climate system, especially El Nino, cause significant temperature changes on shorter timescales, making it difficult to distinguish the effect of forcing by greenhouse gases from natural internal variability. It is, of course, a matter of degree – the longer the record of change the more confident we can be in its cause. However, when we consider the record decade by decade (see below) it is clear that even allowing for uncertainties in the observations, the last three decades have each been significantly warmer than the previous one i.e. the error bars do not overlap. This has not been seen previously in the instrumental record.

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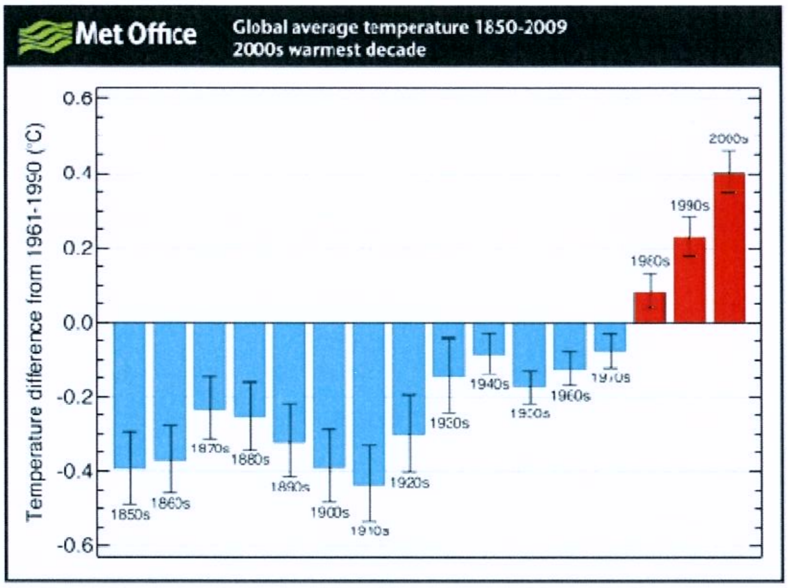

Figure: Observed estimates of decadal global mean temperature differences. The uncertainty in the observed estimates is shown in the error bars.

To address your second point, natural variations in temperature do indeed operate on timescales up to (and longer than) centuries. This is widely recognised. Solar radiation is an example of an external forcing that operates on multi-decadal timescales, and slow climate components, such as the ocean circulation and ice sheets, have important roles on decadal and century time-scales, with ice sheets being particularly important during transitions between glacial-interglacial cycles. (It's worth noting that we are now at the height of an interglacial and therefore the potential for ice sheets to influence significantly the natural climate variability is likely to be relatively small.) There are, of course, uncertainties in our understanding of these factors and their representation in climate models, but scientists go to considerable lengths to take model, forcing and observational uncertainties into account when assessing the certainty associated with conclusions in attribution research.

At its simplest level, it comes down to Ockham's razor. The increase in global average temperature since the mid-twentieth century, as well as the changes observed in a number of other variables, are consistent with scientific understanding of how the climate should respond to the increase in greenhouse gases observed, and are inconsistent with the scientific understanding of how the climate should respond to all known natural external factors (in fact, known natural forcing factors would probably have produced cooling over this period). It is clearly not possible to claim that one can rule out the possibility of another cause of the recent warming, but the evidence clearly shows that greenhouse gases are the most likely cause.

It is also important to note that past changes are not analogues of what is happening to our climate system now. As I have already noted, we are at the height of an interglacial period and human activities have already taken CO_2 concentrations to levels that we have not seen for at least 800,000 years.

You claim that you can be "certain" about the amount of warming that would occur from, say, a doubling of CO_2 concentrations. There is no basis whatever for this. I take it that this 'certainty' derives from climate models, whose reliability depends on the assumptions programmed into them, which may or may not be correct (and are inevitably incomplete, as our knowledge is incomplete). While it may well be that the majority of climate scientists accept the reliability of these climate models, there are many distinguished climate scientists who do not. There is clearly no certainty about all this.

Again, I have been selectively quoted here. In fact, I stated that we can be "reasonably certain" about the value of climate sensitivity. To be more specific, the IPCC AR4 concluded that equilibrium climate sensitivity is *likely* (>66% probability) to be in the range 2°C to 4.5°C, with a best estimate value of about 3°C, and *very unlikely* (<10% probability) to be less than 1.5°C. This assessment is based on analysis of models as well as increasing constraints from observations (including observed temperature changes over the last 150 years, the response of the global climate system to changes in the forcing caused by volcanic eruptions, and proxy records of climate change on longer timescales). The uncertainty that remains is well-recognised and taken into account in projections of future temperature change.

I am baffled why you should apparently feel that referring to carefully selected phenomena such as the extent of sea ice or the advent of spring in the UK proves anything at all about either the extent of any warming that has occurred or its probable cause. The temperature is the

My point in mentioning the decline in Arctic summer sea ice extent and the earlier arrival of spring in the UK was simply to highlight that there are a number of significant lines of corroborating evidence that confirm that the world is warming. These phenomena are not carefully selected but are part of an increasingly comprehensive body of evidence that shows that our climate is changing in ways that are consistent with AGW. In fact, a number of the changes observed over the last few decades have now been attributed to anthropogenic forcing, confirming with a high level of confidence that forcing by greenhouse gas emissions has contributed to the changes observed. These include the systematic increase in the heat content of the top few hundred metres of the ocean (IPCC, AR4) and the rise in global sea level (IPCC, AR4), as well as changes in atmospheric moisture content, global and regional patterns of precipitation changes, and increases in ocean salinity at low latitudes in the Atlantic Ocean (Stott, P.A. *et al.*, 2010 Detection and attribution of climate change: a regional perspective. Wiley Interdisciplinary Reviews: Climate Change 1, 192-211).

The rate of warming over the 20 years from 1980 to 2000 is nothing special. Virtually identical rates of warming were recorded over the 30 years from 1910 to 1940 and the 20 years from 1860 to 1880. Since, according to the IPCC (AR4, p.12), man's influence on the climate became important only after 1960, these earlier warming phases must be due to natural factors (presumably part of the gradual emergence from the Little Ice Age).

First, I should clarify that the IPCC AR4 concluded (p. 10 of the WG1 report) that most of the observed increase in global average temperature since the mid-twentieth century is very likely to be due to the observed increase in anthropogenic greenhouse gas concentrations; this is not the same as concluding that anthropogenic factors had no effect on temperatures before then.

Essentially, our current understanding is that natural factors made a significant contribution to warming during the early 20^{th}-Century (studies vary in the relative roles of solar forcing, volcanic forcing and natural internal variability), but greenhouse gases may also have played a role. As you will appreciate, the uncertainty associated with both the global temperature record and underlying forcing factors is greater in the nineteenth and early twentieth centuries than over recent decades, which makes it more difficult to establish the cause of temperature changes during this period with confidence. I would refer you to Chapter 9 of the IPCC AR4 for a more detailed discussion of the likely causes of past climate change.

I do not see how the fact that the first decade of this century has been warmer than any other decade over the past 150 years proves anything at all. There have been other warm periods in the more distant past.

Again, I feel that I have been rather selectively quoted here. In my original response, I pointed out that the first decade of this century has been warmer than any other decade over the past 150 years in the context of a discussion about the long-term trend in global average temperature and the factors that could be responsible for such a change. As I've already pointed out, if globally averaged surface temperatures are averaged over each decade to remove some of the short term natural variability, the last three decades have each been significantly warmer than the last, revealing a clear upward trend in temperature on decadal timescales.

It is, of course, true that there have been warmer periods in the distant past, especially if you mean by distant, multi-millennial timescales. Variations in the Earth's orbit around the sun are what have driven those past changes, but the trend since 1750 is estimated at only ~$0.12 Wm^{-2}$. These values are an order of magnitude lower than the radiative forcing necessary to produce the observed $0.75^{\circ}C$ warming since pre-industrial times. So past climate changes do not counter the evidence that greenhouse gases were the primary cause of recent warming.

The 10 cm recorded rise in global sea level over the past 50 years, to which you refer, is the same as the recorded rise in global sea level over the previous 50 years, when man's influence is regarded as having been minimal.

The IPCC AR4 confirms that there is high confidence (about an 8 out of 10 chance) that the rate of sea level rise accelerated over the period 1870 to 2000. Sea level is expected to respond relatively slowly to anthropogenic forcing due to the huge inertia in the climate system. Careful detection and attribution work has shown that it is *very likely* (>90% chance) that anthropogenic forcing contributed to sea level rise during the latter part of the 20^{th} century, but uncertainties in observations and forcing mean that it isn't possible to attribute changes before then to specific causes with confidence.

The significance of urbanisation is still contested.

The significance of urbanisation on the global temperature record is not contested by the vast majority of climate scientists. Most stations are not affected by the urban heat island effect and there are well-established ways of taking the effect into account for stations that are (such as comparing temperatures on still and windy nights and excluding urban stations). I refer you to my previous response for further information on this issue.

The IPCC's more than 90% probability claim about the cause of warming over the past 50 years is (so far as I am aware) devoid of any statistical basis.

The IPCC's finding that there is a more than 90% probability that most of the observed increase in global average temperatures since the mid-20^{th} century is due to the observed increase in anthropogenic greenhouse gas concentrations is based on a carefully calibrated assessment of the scientific literature available to the AR4. The scientific literature cited used well established statistical techniques. The assessment accounts for uncertainties due to errors in observations, climate models, and in the forcing factors (both natural and anthropogenic) used to drive climate models (see Table 9.4 of IPCC AR4 WGI).

The effect of sulphate aerosols is simply assumed, as explained in my book: this is sheer curve fitting.

There is well recognised uncertainty in the climate impacts of all aerosol components, including sulphate aerosol, but it is highly misleading to suggest that the effect of sulphate aerosols is "simply assumed" or "sheer curve fitting". The effect of aerosols has been assessed using detailed observational studies (including dedicated field campaigns, laboratory measurements and more routine surface and satellite based observations). Some modelling studies calculate aerosol forcing based on variations in surface emissions and understanding of aerosol physics and chemistry (so-called 'forward estimates' of forcing). Others use 'inverse estimates' of aerosol forcing, in which observational data are used to constrain aerosol forcing. The similarity of

results from inverse and forward modelling strengthens confidence in estimates of total aerosol forcing.

I am surprised that you seek to defend the hockey stick given the evidence that has subsequently come to light of the misuse of statistical techniques and other shortcomings and the recent admissions by Professor Phil Jones that the medieval warm periods (which is now accepted to have been a worldwide phenomenon) may well have been warmer than today. The hockey stick which was used by the IPCC to try and demonstrate the effect of man on the temperature of the planet, and which eliminated the Roman Warm Period, the LIA and the MWP, has been abandoned and replaced even by the very authors who devised it in the first place.

I should clarify that I did not seek to defend the original hockey stick analysis; I am aware that there are issues and uncertainties associated with it. I should also say that my understanding is that there is still much debate over whether the Medieval Warm Period was global in extent and over whether it was warmer than today. But the key point is that the validity or otherwise of this graph, and the magnitude and spatial extent of the Medieval Warm Period, do not have any significant bearing on the cause of recent warming or the conclusion that warming will continue if emissions continue unabated.

So far as water vapour is concerned, I cannot see the significance of the point you are making. But I should add that I have become increasingly puzzled by the proposition that warming brings about more water vapour, and so *on ad infinitum*. This implies a runaway instability which, if true, would have made the planet uninhabitable long ago.

The point I was making with regard to water vapour was to explain that while water vapour is indeed an important and indeed fundamental natural greenhouse gas, in the case of AGW it is a feedback and not a forcing factor.

In response to your question, the existence of a feedback in the climate (or any other) system does not imply a runaway instability. In the case of water vapour, as was established in simple but physically-based models in the 1960s, a CO_2-induced warming leads to an increased concentration of water vapour, which means that the planetary energy balance can only be established at a higher temperature change than would have been the case without the water vapour feedback. The reason why atmospheric water vapour concentrations increase with warming is based on fundamental moist thermodynamics – the Clausius-Clapeyron relationship. We expect from theory that water vapour concentrations will increase by ~6%/K warming. This is what we observe and indeed what our models simulate.

The way in which the planet achieves energy balance is more complex than your simple argument for a runaway instability. The hydrological cycle is a fundamental part of that balance and indeed it is the natural greenhouse effect from water vapour that has made our planet habitable. An explanation of the complete energy balance of the system involving the circulation of the

oceans and atmosphere is something that you should consider, and I would refer you to a range of important papers on this topic by Kevin Trenberth.

Of course the models are based on the fundamental laws of physics. But they also incorporate a large number of assumptions (notably about feedbacks) which are crucial and which may or may not be correct, and of necessity also leave out a large part of climate science which is still unknown, but which may or may not be highly relevant. It would be possible to construct climate models, also based on the fundamental laws of physics, but incorporating a number of different assumptions, which produced different projected outcomes. If the present crop of models had an impressive record of accurate temperature predictions that would indeed appear to validate them. But that is not the case.

There are, of course, uncertainties associated with processes in climate models, as well as constraints of computer power which limit model resolution, so it is clear that they cannot be complete representations of the climate. Also, the chaotic and hugely complex, non-linear nature of the climate system means that we must always consider future projections as probabilities of potential outcomes. But it is hugely misleading to suggest that processes that are not fully understood are "assumed". Rather, they are constrained based on physical understanding of the climate system, which in turn is based on (i) fundamental theories of radiative transfer, dynamics and thermodynamics, (ii) process studies using detailed field and satellite observations and sophisticated process-based models, and (iii) exhaustive comparison with global 4-dimensional analyses of the recent and current climate. The uncertainties that remain are increasingly quantified by using ensemble prediction techniques.

With regard to your last point, models are routinely and extensively assessed by comparing simulations with observations. They show significant skill in representing many important features of the climate (e.g. the large-scale distributions of atmospheric temperature, precipitation and wind) and can simulate essential aspects of many of the patterns of climate variability observed across a range of time scales (e.g. the seasonal shifts of temperatures, storm tracks and rain belts, El Nino cycles and the North Atlantic Oscillation). They are also able to reproduce climate changes in the past (such as the Last Glacial Maximum, and over the instrumental period). It is evidently more difficult to test projections of climate change caused by greenhouse gas emissions in 'real time' due to the timescales involved (as explained above, the signals of greenhouse gas forcing are evident on multi-decadal timescales), but projections have shown skill in this task. You may find the results of a paper by Rahmstorf et al. (Recent Climate Observations Compared to Projections. 2007. *Science*, 316, 709) of interest in this regard. The results of this paper are summarised in the figure below. As time progresses and the evidence of a changing climate continues to emerge, this type of verification will become increasingly important.

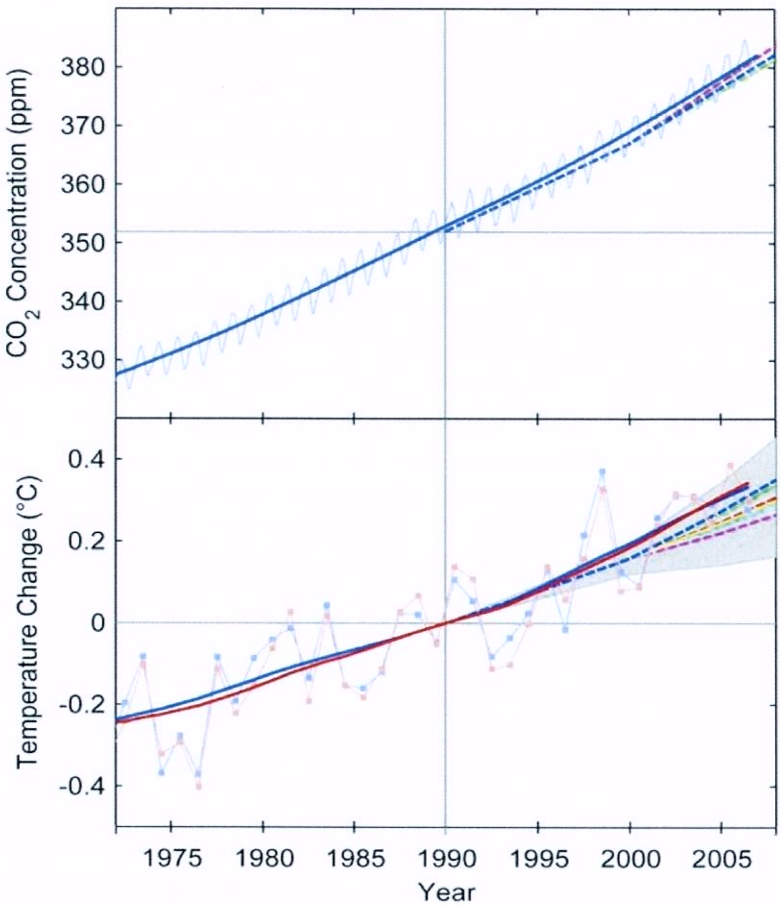

Figure: Predictions of CO_2 levels and global mean surface temperatures from 1991 (IPCC Third Assessment Report) vs. what actually happened. Observed temperatures from Hadley Centre (blue) and NASA GISS (red). Note that the various emission scenarios used in AR3 slightly underestimated the actual CO_2 levels which have exceeded even the high emission scenario. Temperature projections all gave warming, but suggested slightly less warming than observed, possibly attributable to improving air quality (see http://www.pik-potsdam.de/~stefan/Publications/index.html).

I hope this is helpful in clarifying the scientific points you have raised.

I am sure you will appreciate it would be difficult to continue our correspondence in anything like the level of detail it has recently taken, but I am sure the scientific discussions will continue.

Sir John Beddington