# Questions addressed to Sir John Houghton

# Questions for the Record
# Senator Bingaman

## QUESTION 1

Over the last several decades, anthropogenic emissions have "substantially contributed" to the increase in average global temperatures. Upon receiving a question from one of the Senators, one of the panelists suggested that "80 percent" of the warming was due to human activities. Do all the panelists agree? Please provide information as to how this estimate was derived.

## ANSWER

I was not the panelist that quoted the 80%. It is, however, close to the estimate that I have also often quoted quite independently and arrived at as follows. In answering the question of how much of the recent warming is due to human activities there are two relevant considerations: (1) estimates of radiative forcing and (2) estimates of natural variability. I deal with these in turn.

*Estimates of Radiative Forcing*

It is the radiative forcings that are driving change. For the latest estimates of radiative forcings I refer to the paper by J. Hansen et al, *Earth's Energy Imbalance: Confirmation and Implications*, in Sciencexpress for 2 May 2005 – a paper that provides more detail and updates similar information in Fig 3 in the Summary for Policymakers (SPM) and in chapter 6 of the IPCC 2001 Report, *Climate Change 2001: the Scientific Basis*.

'Natural' forcings are mainly those due to volcanoes (in Hansen's paper the blue line labelled stratospheric aerosols - because it is dust in the stratosphere that causes forcings from volcanoes) and changes in solar irradiance. The estimated solar irradiance change of about 0.2 watts per square metre occurred mostly in the first half of the 20th century and is believed to be a significant factor in leading to the warming during that period. Changes in solar radiation in the second half of the century are small as indicated from measurements from satellite instruments since the 1970s.

The other forcings are almost entirely anthropogenic (apart from a small component of black carbon from 'natural' forest fires). Note that greenhouse gases provide by far the largest positive (warming) forcing and that significant negative (cooling) forcing comes from anthropogenic aerosols. This latter is sometimes called global dimming as it tends to offset some of the greenhouse gas warming. Note that by far the largest contribution to radiative forcing over the last 50 years comes from increases in greenhouse gases and that at least 95% of the positive (warming) forcing over this period comes from human activities. Note also that most of the negative forcing is also of human origin and that this will reduce if, as is expected, sulphur dioxide (that leads to reflective tropospheric aerosol formation) pollution controls become more severe during coming decades.

Fig 1B in the Hansen et al paper compares model simulations of surface temperature change over the 20$^{th}$ century, that include all the forcings of Fig 1A, with observations of surface temperature change. It should be compared with Fig 4 in the SPM of the IPCC 2001 Report. It deals more comprehensively and accurately with the various forcings than did the IPCC Report and extends them to the present. It shows a remarkable degree of agreement between simulations and observations.

*Estimates of Natural Variability*

Looking at estimates of anthropogenic radiative forcing enables us to establish that the observed warming over the last 50 years is entirely consistent with it being due almost entirely to human activities. However, it is known that the global average temperature and hence the climate can also change due to unforced variations that occur because of variations within the climate system itself. Estimates of such natural variability come from long climate model simulations that agree reasonably well with such variability found in observational studies (as explained in chapters 8 and 12 of the IPCC 2001 Report,). Such studies show that more than about 20% of the rise in global average temperature since 1950 of about 0.45 ºC is very unlikely (less than 10% probability) to come from natural unforced variability.

Taking these two considerations together leads to the conclusion that it is very likely (greater than 90% probability) that at least 75% of the warming over the last 50 years in due to human activities.

## QUESTION 2

We received testimony that sought to distinguish between average global temperature changes causes primarily by anthropogenic emissions and local / regional temperature changes caused at times by natural variation. Please explain in greater detail.

## ANSWER

The climate shows natural variability (i.e. unforced variability – see answer to question 1) in all climate characteristics (temperature, precipitation, humidity, wind speed etc) and on all time and space scales. The shorter the time scale and the smaller the space scale the larger is this variability. That is why it is easier to identify trends in climate due to anthropogenic emissions in annual and global averages of quantities such as temperature rather than in shorter-term or local climate data.

Climate regimes are patterns of climate behaviour that have been identified in different regions. They represent an important component of the description of climate in different parts of the world. Examples of these regimes are the Pacific North Atlantic Anomaly (PNA), the North Atlantic Oscillation (NAO) and the El Nino- Southern Oscillation (ENSO). The last of these is the best known and the most important; El Nino events are associated with extreme climate events such as floods and droughts in Africa, Australia, America and Asia. There seems no doubt that these regimes are influenced by increases in greenhouse gases; understanding the detail of these influences is an important topic of current research.

## QUESTION 3

Please explain the meaning of 'scientific consensus' and comment on the status of the science of climate change in the scientific and academic community.

## ANSWER

Because discussion and debate are essential to the advancement of science, use of the expression 'scientific consensus' needs to be explained. In the context of the IPCC reports 'consensus' does not mean that agreement has been reached on all matters concerning climate change. What the IPCC has done in its reports is to distinguish between what is reasonably well known and understood from those areas where there is still much uncertainty and debate. What is often described as the IPCC 'consensus' (although the IPCC itself has never used that term) concerns matters such as the estimates of global average temperature rise (including its range of uncertainty), the range of estimates of sea level rise and the descriptions of likely dominant impacts in terms of precipitation and extremes – all under stated assumptions regarding future anthropogenic emissions.

The IPCC Reports have been given very strong support by many scientific bodies including most recently in a statement issued on the 7 June 2005 by the Academies of Science of the leading nations of the world (the G8 countries plus China, India and Brazil).

The science of climate change has grown very substantially over the last twenty years – so has the number of scientists working in the field. It has become an increasingly well established and respected academic discipline. Climate data has expanded a great deal and climate models have developed in size (thanks to increased computing power) and sophistication. Modeling of regional change is now developing rapidly into a useful and effective tool for the analysis and projection of regional changes. As the science has advanced, not only have the basic messages regarding climate change in the IPCC's 1990 and 1995 Reports been confirmed but the impacts then projected have proved, in general, to be too conservative.

## QUESTION 4

What is "abrupt climate change?" Can you identify any potential thresholds that might be crossed if insufficient action is taken to control CO2 emissions? For example, I have heard that beyond certain temperature increases, large ice sheets could collapse, leading to huge increases in sea level. Can you comment on this and other potential thresholds?

## ANSWER

The climate system is complex and highly non-linear in character. 'Abrupt climate change' refers to the possibility of unusual and rapid change occurring due to thresholds being reached or instabilities occurring. Some examples are:

1) If the average temperature in the vicinity of Greenland rises by more than about 3ºC (5.5ºF) – very likely to occur within the next 50 years - studies indicate that melt down of the Greenland ice sheet is likely to begin (*Climate Change 2001, the Scientific Basis* IPCC 2001 Report, chapter 11). Complete melt down, that could take 1000 years or more, would lead to 7m (23 ft) of global sea level rise.
2) There is a lot of current concern regarding the stability of the West Antarctic Ice Sheet. It could lose mass over the next 1000 years with an associated sea level rise of several meters but there is incomplete understanding of some of the underlying processes (*Climate Change 2001: Synthesis Report,* IPCC 2001, Report Q4).
3) The long term stability of the ocean's Conveyor Belt (a circulation in the deep ocean coupling the oceans together) is also of concern. It is partially driven by the Thermohaline Circulation (THC) whose main source is the sinking of cold, dense water with high salinity at high latitudes in the Atlantic ocean. Increased precipitation at these latitudes and increased ice melt reduces the water's salinity, and hence its density, making it less likely to sink, so weakening the THC. All climate models that couple the ocean and atmospheric circulations show this weakening of the THC and hence also of the Gulf Stream. It is possible for the THC to be cut off completely – some models with 'business as usual' growth in $CO_2$ emissions show cut-off occurring within 100 - 300 years; there is also paleoclimatic evidence of it occurring in the past. If cut-off were to occur, the effect on the world's climate, especially in regions surrounding the north Atlantic, could be profound (*Climate Change 2001, the Scientific Basis* IPCC 2001 Report, chapters 7 and 9).

## QUESTION 5

Can you tell us something about the time horizon for stabilizing climate, given how long carbon dioxide remains in the atmosphere? Do we need to begin to control emissions now or can we wait?

## ANSWER

There are three main time scales concerned with the stabilization of climate.

The first is the time response of the oceans to change. If emissions of greenhouse gases were to end immediately, the global average temperature would continue to rise at a similar rate as now for 30 to 50 years as the ocean's upper layers warm and then much more slowly over centuries as the lower layers of the ocean warm.

1) The second time scale is concerned with the life time of carbon dioxide in the atmosphere that is largely determined by exchange with the ocean. Its life time in the atmosphere is complex but is typically of the order of decades (for exchange with the ocean's upper layers) and centuries (for exchange with the deeper ocean). If anthropogenic input of carbon dioxide to the atmosphere were to halt, its atmospheric concentration would only decline slowly.
2) The third time scale of importance is that applying to changes in anthropogenic emissions. Because of inertia in the system of energy infrastructure, changes in these emissions will take the order of decades to be realized.

For reasons associated with all these time scales – reducing the build up of further commitment to change associated with (1), recognizing the long time scale for emissions reductions to be reflected in the atmospheric carbon dioxide concentration with (2) and the time scales associated with energy infrastructure in (3) – there is an urgency to begin seriously to reduce emissions now.

## QUESTION 6

Given that there is still some uncertainty about the details of future warming, how should such uncertainty be dealt with in designing policy responses?

## ANSWER

The need for appropriate policy responses despite scientific uncertainty was recognized 13 years ago in 1992 in the Framework Convention on Climate Change agreed by all nations at the Earth Summit in Rio de Janeiro, signed by President George Bush Senior for the United States and subsequently ratified unanimously by the US Senate. In Article 3 it includes an agreement that the Parties to the Convention should "*take precautionary measures to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects. Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing such measures, taking into account that policies and measures to deal with climate change should be cost-effective so as to ensure global benefits at the lowest possible cost.*"

Scientific certainty regarding many aspects of climate change has increased substantially since 1992 so that the need to take action is even stronger that it was then. A range of responses can be designed.

There are responses addressing energy efficiency e.g in buildings, appliances, vehicles and in industry. Many of these will require regulation or incentives for them to be achieved on the scale required. Most of them are win-win in character, as most will lead to significant –even large- savings in cost or materials as well as in carbon emissions. There are numerous examples, for instance from US industries, showing the value to the US economy of such measures.

1) There are responses that also enhance energy security that are also win-win.
2) There are responses to do with adaptation to climate change, for instance to prepare, especially in the more vulnerable areas, for the expected increase in the number and intensity of extreme events (e.g. floods, droughts, heat waves). There is much evidence to show that more adequate preparation substantially reduces the damaging impacts of such events.
3) There are responses that would be much more cost-effective to take now rather than later, for instance in the design of power infrastructure with a typical life of 30-50 years. To have to replace such infrastructure before the end of its useful life would be costly.
4) There are technologies concerned with carbon-free energy sources (e.g. solar, biomass, biofuels, hydrogen technologies) that need to be developed as rapidly as possible to the level at which they can begin to act as significant alternatives to conventional fossil fuel energy sources.

## QUESTION 7

How do we know that emissions of carbon dioxide and other greenhouse gases are causing Earth's temperature to rise, as opposed to other factors that we have no control over; such as sun spots? Some assert that an increase in solar irradiance is the main cause of the Earth's current warming trend. Therefore, reducing fossil fuel emissions would not impact the Earth's temperature.

## ANSWER

Measurements of solar irradiance have been made since 1979 from satellite mounted instruments. Small changes of up to 0.1% occur associated with the 11 year solar cycle. There is no evidence for changes greater than about 0.2% occurring in the longer term. Over the last 50 years, radiative forcing due to changes in solar irradiance is much smaller than that due to anthropogenic increases in greenhouse gases (*Climate Change 2001, the Scientific Basis* IPCC 2001 Report, chapter 6 and J. Hansen et al, *Earth's Energy Imbalance: Confirmation and Implications*, in Sciencexpress for 2 May 2005 doi 1110252).

## QUESTION 8a

There are some who question the veracity of the assertion that the earth has warmed substantially over the last century. Arguments typically fall into three categories. It would be useful if you would address each in turn:

a. Urban Heat Island Effect. This is the claim that the underlying temperature data is tainted by the proximity of data-generating thermometers to cities. As urban areas have grown over the last fifty years, the air temperatures around these cities have increased due to larger amounts of heat generating substances like rooftops and roadways. Scientists claim to have corrected for the urban heat island effect. How was this done, and how can we be sure that it was done correctly?

## ANSWER

During development of the global surface temperature compilations, data from each observing station were quality-controlled. This included comparisons with neighbouring stations. Records showing complex inconsistencies relative to their neighbours were rejected from the analysis. This will have removed many urban stations where ongoing changes in the environment have caused multiple, non-climatic changes in the record. Where the neighbour-comparisons showed simpler inconsistencies such as a relative warming trend, the urban records were retained but were adjusted to be consistent with their rural neighbours (e.g. Hansen, J. et al, 2001, *J. Geophys. Res*., **106**, D20, 23,947-23,963).

There is substantial evidence that this procedure has been successful and that the land surface air temperature record used in assessment of climate change is not greatly influenced by urban warming. First, global rural temperature trends have been very similar to those based on the full network of stations (Peterson, T. C. et al, 1999, *Geophys. Res. Lett.* **26**, 329-332). Secondly, ocean surface temperatures have risen nearly as much as those over land (Folland, C. K. & Karl, T.R. et al 2001, chapter 2 in *Climate Change 2001: The Scientific Basis*. IPCC 2001 Report). A somewhat greater warming over land than over the ocean under increasing greenhouse gases is expected because of the greater thermal capacity of the oceans. Thirdly, temperatures on calm nights, when urban heat islands are mainly evident, show no more warming than temperatures on windy nights at a worldwide subset of the stations used to monitor global surface air temperature (Parker, D. E., 2004, *Nature,* **432,** 290).

Uncertainties regarding urbanisation effects are allowed for in the global average surface temperature curve shown in the IPCC 2001 Report (*Climate Change 2001: The Scientific Basis,* Summary for Policymakers, Figure 1a). These uncertainties play a diminished role because land is only 30% of the global surface. Even the overall uncertainties, which include the effects of incomplete coverage and possible residual biases are much smaller than the global warming signal.

## QUESTION 8b

b. Satellite and Airborne Balloon Data Contradict Surface Temperature Readings. Global mean temperature at the earth's surface is estimated to have risen by about half a degree F over the last two decades. On the other hand, satellite measurements of radiances and airborne balloon observations indicate that the temperature of the lower to mid-troposphere (the atmospheric layer extending from the earth's surface up to about 8 km) has exhibited almost no change during this period. Please explain whether this discrepancy is, indeed, real and how to account for it.

## ANSWER

Over the last few years, much careful and detailed study has been addressed to surface, balloon and satellite temperature observations taken over the last 25 years and the relationships between them. I summarize briefly in this answer the conclusions from a number of key papers that are now available describing this work, some of them published as recently as this August and two that will be published over the next two or three months. Because of the number of papers to which I am referring, for convenience I list all the references at the end of this answer. The main outcome of this work is that statements that the lower to mid-troposphere shows no warming trend or has cooled relative to the surface are no longer tenable. Such statements rely upon analyses of old radiosonde datasets, which had not adequately accounted for instrumental and observational biases, and a single satellite dataset. The first US Climate Change Science Program report (www.climatescience.gov), which will be published in the late fall, is on this subject and will provide a far more detailed answer than is possible here.

Efforts in the last few years have led to significant revisions to existing upper-air temperature datasets and the production of a number of new balloon-based (Lanzante et al., 2003a,b, Thorne et al., 2005a) and satellite-based (Mears et al., 2003, Grody et al., 2004, Mears and Wentz, 2005) climate datasets under different, seemingly reasonable, approaches. An alternative approach to removing the stratospheric influence from the satellite records has also been proposed (Fu et al., 2004). Therefore the scientific community now have at their disposal a much larger number of independently derived estimates of tropospheric temperature change to analyse. Globally, the estimates of the average temperature trend for the period over which satellite data are available range from a slight warming to warming greater than that seen at the surface. It can be concluded therefore that the tropospheric data are consistent with a temperature trend similar to that at the surface, although the uncertainties are such that a relative cooling of the troposphere also cannot be ruled out.

Uncertainty in tropospheric trends is much greater than uncertainty in surface trends, reflecting the greater technological challenges of adequately monitoring changes aloft than at the surface. Only with the advent of recent datasets (see above) has the importance of structural uncertainty – the effects of methodological choices employed to identify and remove non-climatic influences from the raw data during dataset construction upon the climate dataset that results – become apparent (Thorne et al., 2005b).

Much of our uncertainty in temperature trends aloft arises in the tropics. Mears and Wentz (2005) have highlighted an error in the original satellite record of Christy et al. (2003) which led to a spurious cooling bias in the tropics. Balloon-based records are also sparsely located in the tropics, and have tended to launch only at local daytime (rather than twice-daily that is more common elsewhere). Daytime biases in radiosonde records are more pervasive due to solar-heating effects, and the lack of day and night launches at these stations potentially makes identification and removal of any non-climatic influences much harder (Lanzante et al., 2003a, Sherwood et al., 2005).

Santer et al., 2005 have recently compared tropical temperature predictions from 19 climate models run with historical changes in human-induced and natural forcing factors with four of the current observational datasets (2 balloon based, 2 satellite based). Within the tropics our expectations are that surface anomalies will be amplified aloft because of latent heat release upon condensation under a convective regime. All the models exhibit this behaviour on all timescales from monthly variability up to inter-decadal trends regardless of differences in model physics, resolution, and the forcings applied. The observations also exhibit amplification aloft on short timescales, but all except one dataset exhibits damping aloft on long timescales. Either in the real-world different processes dictate low- and high-frequency behaviour in the tropics and all the models fail to capture this, or, more plausibly, most observational datasets retain significant biases which impact their suitability for long-term trend analysis. Gaining unambiguous clarification of which is the case and gaining a cleaner estimate of recent tropospheric temperature changes in the tropics is seen as a high priority.

## References

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## QUESTION 8c

c. The Hockey Stick. In recent months, there have been assertions that the statistical method used to analyze global temperature data for the last several hundred years was biased towards generating the "hockey stick" shaped curve that shows sustained low and stable temperatures for hundreds of years with an extremely sharp rise in the last 100 years. Can you comment on whether the observations depicted in the hockey stick curve are, indeed, legitimate?

## ANSWER

I have received a similar question from Senator Talent (Q6). I provide the same reply to both questions.

This is a fast moving area of research. Very recently the assertions by McIntyre and McKitrick (2005a, b) (MM), alluded to in the question (references at end of answer), have been shown by several papers to be largely false in the context of the actual data used by Mann and co-workers. Ammann (a palaeontologist at the National Centre for Atmospheric Research) and Wahl of Alfred University have two papers, one in review and one in press, that reproduce the original results published by Mann et al in Nature in 1998 and Geophysical Research Letters, 1999 and prominently used in the IPCC Third Assessment Report. They demonstrate that the results of MM are due to MM having censored key proxy data from the original Mann et al (1998) data set, and to having made errors in their implementation of the Mann et al method. They specifically show that fifteenth century temperatures, related to the bristlecone pine issue, were not similar to twentieth century temperatures, as was suggested by MM. Amman and Wahl issued a press release in May 2005 on this finding. Fuller details are at
http://www.ucar.edu/news/releases/2005/ammann.shtml
These authors state that they will make their full computer code available publicly.

A specific claim is made by MM that the "hockey stick" shape of the Mann et al reconstructions is derived from the way Mann et al normalise and centre their principal component pattern data. This has recently been tested. Rutherford et al (in press, Journal of Climate) have shown that essentially the same result as Mann et al is obtained using an entirely independent statistical method on similar data. This eliminates the step of representing regional tree-ring networks by principal components. The likely reason why Mann et al were able to successfully use their particular technique is because the structure of paleoclimate data is more complex than the temporal "red noise" tested by MM.

Other investigators have reconstructed climate over the past 1000 years using very different techniques and different selections of data. Some of these results are recent, and some were shown in Fig 2.21 of the IPCC Third Assessment Science Report, Climate Change 2001. These authors tend to find a greater magnitude of climate variability than did the Mann et al "hockey stick" results. In particular the "Little Ice age" centred around 1700 is generally cooler. Some of the more recent papers of this type show a Little Ice Age cooler by up to several tenths of a degree centigrade than any reconstruction shown in the Third Assessment Report in Fig 2.21, including that of Mann et al. However, all but one recent papers (Esper et al, 2002, Mann & Jones, 2003, Moberg et 2005, Huang, 2004, Jones & Mann, 2004, Bradley et al ,2003) find that the warmth of the late 20th century is still exceptional, as their reconstructions of the temperature level relative to the 20th century in the Medieval warm period are similar to the Mann et al results. Soon & Baliunas concluded that the late 20th century was not unusually warm but their methodology was flawed (Mann and Jones, 2003) as they equated hydrological influences with temperature influences and assumed that regional warmth corresponded to hemispheric warmth.

I am sure that the IPCC Fourth Assessment Report will fully take all these new findings into account. In the meantime, it is important to recognise that no evidence has emerged that seriously calls into question findings regarding the climate of the 20$^{th}$ century and the influence of human activities as described in the IPCC 2001 Report.

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## QUESTION 9

Some say that global warming might be a positive development? Will agricultural crop productivity improve due to the greater amount of CO2 in the atmosphere, and can we expect the Arctic and Antarctic regions to become more habitable?

## ANSWER

*On crop productivity*

Higher concentrations of $CO_2$ can enhance the productivity of crops that undergo C3 photosynthesis (wheat, rice and most temperate crops) by fertilizing photosynthesis. In areas subject to water stress, productivity may also potentially be enhanced through higher $CO_2$ concentrations increasing the efficiency of water use. Crops with C4 photosynthesis (maize, sorghum, millet, sugar cane) will not benefit from increased $CO_2$ in these ways.

These direct effects of $CO_2$ on crops should be viewed in the context of indirect effects due to the climate change arising from increasing $CO_2$. Crops are affected by changes in temperature and moisture availability. Warming in cold regions is expected to create generally more favourable conditions for crops, although the expansion of crop areas would be limited by soil quality and day length. In regions currently under agriculture, the specific types of crops which may be grown are expected to change with warming; C4 crops may become more favoured in temperate regions. However, higher temperatures would be expected to lead to a greater requirement for irrigation due to increased water loss by evaporation. Warming may also increase the prevalence of some pests and diseases.

Moreover, changes in precipitation patterns could have major impacts. Some regions are predicted to become wetter and others drier. Wetter conditions in general would promote growth although increased severe heavy rainfall and floods would damage crops. Drier conditions in general would place greater demands on irrigation which itself would be

subject to decreasing supply and competition from other uses such as drinking water and industry. Extreme high temperatures and droughts could have catastrophic impacts. In summary, some regions would expect net positive impacts whilst other would expect net negative impacts. Research on cereal yields assessed in the IPCC Third Assessment Report, which should be regarded as early work in an ongoing field of research, suggested that the greatest decreases in yield are expected in the tropics while some temperate and cold regions may see an increase in yield in the medium term.

It should also be noted that other changes in atmospheric chemistry related to climate change may affect crop yields. In particular, increases in ozone concentration are expected to be detrimental.

*On habitability of the Arctic and Antarctic*

There may be an expansion of cropping regions towards/into the Arctic, although this would also be limited by other factors as described above. In general, the problems associated with extreme cold temperatures would be expected to decrease. New issues would arise with warming, such as ground subsidence due to permafrost melting. Antarctica is expected to remain ice covered for the next century and beyond.

## QUESTION 10

It is my understanding that the assessments of the progression of global warming through the next century and its impacts on changing the Earth's climate are largely based on computer modeling. It goes without saying that the planet's atmospheric, hydrologic, and meteorological systems are highly complicated. What can you say about how climate modeling capabilities have advanced since scientists began evaluating the problem? What is the level confidence that the computer models are providing useful projections of the future climate?

## ANSWER

*How have climate modeling capabilities advanced since scientists first began evaluating the problem?*

Since the early days of modern climate modeling in the 1970s, scientists have progressively modeled more of the processes that play a role in climate. For example, early models represented only the atmosphere, with a very simple representation of ocean effects. Later the effects of changing ocean currents and ice were taken into account, and recently scientists have begun to model the interactions of climate with the biosphere. At the same time, our developing understanding of each system (atmosphere, ocean etc), together with increasing computer power, have meant that each component can be represented with greater realism.

As an example, today we are able to represent the circulations of the atmosphere and the ocean coupled together with sufficient realism that models reproduce many of the observed, large scale features of climate. Ten years ago this was only possible with the use of so-called 'flux adjustments' which corrected for the long term effects of slight errors in the models' heat distribution. Ten years before that we had not even begun to include the effects of ocean currents in models.

The ongoing development of models has led to increasing confidence in the modeling of many climate phenomena such as El Nino, monsoons, Arctic climate processes and the North Atlantic Oscillation.

Throughout this history of development, the models' prediction of a substantial global warming in response to increasing greenhouse gases has been consistent and unambiguous. As models improve we are able to add more detail and confidence.

*What is the level of confidence that the computer models are providing useful projections of future climate?*

Confidence in model projections comes from three sources: the fact that they are based in fundamental physical principles such as conservation of energy, the fact that when driven by present day levels of solar energy input and concentrations of greenhouse gases and other trace species, they reproduce many observed features of present climate, and the fact that when driven by historical variations in those factors, they reproduce observed variations in climate. The development over the past 20 years of model formulation (discussed above) has seen a parallel increase in the veracity with which the models represent observed climate changes and variability.

The success of models in reproducing present and past climate lead us to believe that they are capturing much of the fundamental physics of the climate system. Hence the comprehensive climate models provide the best tool available to assess future climate change. Nonetheless there are quantitative differences between projections made with different models, and these differences represent a level of uncertainty in the modeling. By detailed analysis of the models, scientists can identify sources of uncertainty – for example the modeling of clouds continues to be an important issue – and by a painstaking process of research reduce that uncertainty over time. Models generally have greatest skill on larger scales, and as a generalization, the larger the scale (global, continental) the more robust are the modeling results.

## QUESTION 11

It is often asserted, by those who dispute the strength of the evidence of human-caused climate change, that the IPCC process has been politicized in a way that has tended to exaggerate the evidence for the reality of the problem and to understate the uncertainties. As the Chair of the IPCC's Working Group I on the science of climate change itself, could you characterize for us any political pressures you and your Working Group have experienced?

## ANSWER

First, let me say that, as chair of Working Group I, a crucially important task for me was to ensure that any bias, agendas or pressures for political or other reasons (for instance personal agendas) were not allowed to get in the

way of accurate, honest and balanced appraisal of the science.

During my years working with Working Group I, although I was supported in that task by the UK government, I played no part at all in the formulation or presentation of UK policy on climate change. The UK government made it clear that they expected me to avoid and refuse all political or other improper interference from whatever quarter in my IPCC work.

The occasions when political pressures were most apparent were the intergovernmental meetings when the Summaries for Policymakers (SPM) were discussed and approved. At these meetings, typically about 100 governments were represented and about 40 scientists representing the lead authors of the chapters were present to ensure the scientific integrity of the final document. The meetings were also open to representatives of non-governmental organizations from both the environmental and industry sides. The purpose of these meetings was to make sure that the SPMs were accurate and balanced scientifically and also that their presentations were clear, understandable and policy relevant.

The political pressures at these meetings that tended to be the most obvious and persistent came from a small group of oil producing states assisted by some of the industrial NGOs who worked to weaken or remove statements expressing the reality of climate change and its likely impacts. Less persistent pressures to strengthen such statements tended to come from some of the environmental NGOs and from a few country delegates. All proposals for change arising from these pressures were subjected to careful scientific scrutiny. After this thorough scrutiny (sometimes taking a substantial amount of time) the final text was accepted by all parties and all scientists without dissention - with one exception that occurred in 1995 when it became necessary to add a footnote expressing dissention by two countries, a footnote that was in fact withdrawn before the document's publication.

The final summary in each case was as accurate, balanced and unbiased as it was possible to make it. In every case, the SPM was improved in both accuracy and clarity by the process of the intergovernmental meeting. I can say categorically that there was no tendency to exaggerate evidence for the reality of the problem or to understate the uncertainties. If anything, the tendency was the other way - to be cautious in our statements and to make sure that we fully represented the uncertainties. The growth in the confidence expressed by the IPCC in its statements from the 1990 report through the 1995 report to the 2001 report, I believe, illustrates the IPCC's tendency to caution.

## QUESTION 12

In the 1970s, climate scientists claimed that the world was cooling and anthropogenic activities might be prematurely forcing the planet into an ice age. Today we hear that the earth is warming. What can you say about the scientific debate on cooling several decades ago and why is today's situation with global warming different?

## ANSWER

There were some very cold winters in Europe and North America in the 1960s that led some scientists to speculate that we might be entering a new ice age. Most climate scientists disagreed with and indeed opposed that speculation - as I did - pointing out that there was nothing in the 1960s outside the range of natural variation. Also, according to the theory that ice ages are triggered by regular variations in the Earth's orbit that can be predicted precisely from astronomical data, the current interglacial period has tens of thousands of years to run before the appropriate conditions for the next ice age occur.

The current situation with global warming is very different. First, the basic physics of increasing surface temperature with increasing greenhouse gases has been known since the early 19$^{th}$ century. Secondly, the increase in global average temperature during the last 50 years is very unlikely to be due solely to natural variability. Thirdly, climate models that include the relevant physics and dynamics of the atmosphere's and ocean's structure and circulation are unable to simulate the profile of temperature increase unless the radiative forcing due to the anthropogenic increase of greenhouse gases is included in addition to all known natural forcings.

# Questions for the Record
# Senator Bunning

## QUESTION 1

Would you say that the steps America has taken in the recent years to improve energy efficiency and produce

lower carbon emissions from power generation are the right first steps in addressing climate change? Within that construct, given the current U.S. electricity supply that is more than 50% derived from coal, is encouraging clean coal technology, IGCC and carbon sequestration the most important immediate policy action we can take?

## ANSWER

I agree that increasing energy efficiency across the board (e.g in buildings, appliances, vehicles and in industry) is an essential part of action to address climate change. It has the advantage that most such actions are win-win in character i.e. they will lead to significant, even large, savings in cost or materials as well as in carbon emissions. There are numerous examples, for instance from US industries, of the economic and other benefits of increased efficiency.

The other main action to address climate change mitigation is for the generation of energy to move as rapidly as possible to be less carbon intensive and eventually to be close to carbon free. It is clear that clean coal technology (IGCC and carbon sequestration) will play an important role in this future.

## QUESTION 2

Sir Houghton, you testified that over two thirds of the projected increase in emissions from now until 2030 will come from developing countries. Do you believe it would be responsible for EU countries and America to adopt an emissions reduction that failed to include this part of the world?

## ANSWER

Countries who have joined the Kyoto Protocol have adopted emissions reductions that do not include developing countries. This is in line with the Framework Convention on Climate Change (FCCC) agreed by all nations in 1992 that states that industrialized nations that have already received large benefits from fossil fuel energy should be first to take action on climate change. But I agree that any international agreements post-Kyoto for emissions reductions need also to involve developing countries, especially those that are industrializing rapidly. I say a little more about this in my answer to Q3.

## QUESTION 3

You indicated in your testimony that America needs to take a global leadership position on climate change. You argued that developing nations will "follow, not lead" on the issue of climate change and that mandatory agreements with these nations would not be necessary as they voluntarily adopt emissions standards in the future. Yet the mandatory cap program recommended by the NCEP specifically discounts voluntary cap programs in America as unable to achieve necessary reductions. They have argued that without mandates, the marketplace will not make the adjustments needed to achieve the very aggressive goals envisioned. Do you believe it is consistent to advocate a "follow, not lead" voluntary approach with developing nations while dismissing the same approach in America?

## ANSWER

Let me explain the arguments behind my use of the phrase 'follow, not lead' in respect of developing countries.

As I explained in my written testimony, we in the developed countries have already benefited over many generations from abundant and cheap fossil fuel energy – although without realizing the potential damage to the climate and especially the disproportionate adverse impacts falling on the poorer nations. The Framework Convention on Climate Change (FCCC) recognized the particular responsibilities this placed on developed countries to be the first to take action and to provide assistance (e.g. through appropriate finance and technology transfer) to developing countries for them to cope with the impacts and to develop cost effective sources of energy free of carbon emissions. This is at the basis of my 'follow, not lead' approach.

But it is not my intention to associate this approach only with voluntary action. Given the fact of first action taken by developed countries, for instance through the Kyoto Protocol, I agree that further action with mandatory targets and requirements are necessary for all countries. That is the urgent challenge of the next stage of negotiations that is taking place within the FCCC in which all countries – both developed and developing - must be involved.

## QUESTION 4

While you have presented what appears to be a united scientific front in the form of the statement from the academies of science from 11 countries, I am concerned by some of the news since the release of that statement. The Russian Academy of Sciences says it was misrepresented and that Russian scientists actually believe that the Kyoto Protocol was scientifically ungrounded. I am also aware that there was a significant misrepresentation on the science between our academy and the British representative. Given this background, wouldn't you say there are still some pretty fundamental disagreements about the science of climate change among scientists around the world?

## ANSWER

I have consulted the Royal Society in London about the questions you have raised about the joint statement from the academies and they have provided me with the information that follows in the rest of this answer.

All of the national academies that signed the joint statement on global climate change remain committed to it, and there is not, nor has there ever been, any disagreement between the signatories over its content.

There have been media reports that a member of the Russian Academy of Sciences, who is well-known for his opposition to the Kyoto Protocol, has requested that the Academy's President, Professor Yuri Osipov, should withdraw his signature from the joint statement. Professor Osipov has not done so.

There has been an exchange of correspondence between Dr Bruce Alberts, the President of the National Academy of Sciences, and Lord May of Oxford, the President of the Royal Society, about a brief reference in the Society's media release accompanying the launch of the statement to an earlier report published by the NAS in 1992. The exchange of correspondence has not been about the content of the joint statement.

The signatories to the joint statement by the national academies remain committed to its content and hope that it will help the governments of the G8 nations to determine their future actions and policies on climate change.

## QUESTION 5

In this international academies statement, you find that an "immediate response that will, at a reasonable cost, prevent dangerous anthropogenic interference with the climate system," but continue to say in the following paragraph, "minimizing the amount of this carbon dioxide reaching the atmosphere presents a huge challenge." Could you please elaborate, since any response can't both be a "reasonable cost" and a "huge challenge" proposition, how you resolve the two?

## ANSWER

The next paragraph in the academies statement goes on to say, *'There are many cost-effective technological options that could contribute to stabilizing greenhouse gas concentrations. These are at various stages of research and development. However barriers to their broad deployment still need to be overcome.'* The barriers that exist are not all economic ones. That this is the case is illustrated by the fact that it is generally agreed that many energy efficiency measures exist that could be implemented at no net cost or with significant cost savings – yet little action is taken about them. Other measures have been proposed that are described as win-win, implementation of which is not being pursued.

One of the barriers is the wide campaign of misinformation by vested interests that has persuaded people and their leaders to deny the existence of the problem of climate change or that even if the problem exists, little or no action about it need be taken at the moment.

An important part of the challenge, therefore, is first to ensure that governments, industries and the general public receive accurate and honest information that will give them the confidence to act, and secondly for governments in particular to set up the framework (including incentives and other appropriate economic measures) that will lead to action at reasonable cost. A further challenge in this process will be to carry out honest assessments of the 'reasonableness' of the costs of mitigation action by comparing them against the costs of inaction and the costs of adaptation, including so far as possible 'costs' that cannot be expressed in monetary terms.

## QUESTION 6

Several scientists have cited events like the high temperatures in Europe in the summer of 2003 and increased storminess in the 1980s and 1990s as evidence of climate change. Don't global ecosystems go through natural periods similar to these as well?

## ANSWER

There is a great deal of variability in the natural climate system and extreme events occur – and always have occurred – on account of this natural variability. Because of this variability it is not possible, in general, to identify any particular extreme event as due to the increase of greenhouse gases through human activities. However, in mentioning the heat wave in Europe in 2003, in which over 20,000 people died, you cite the one recent event that is so very far outside the range of natural variability (the average temperature for the months of June, July and August in central Switzerland was 5 standard deviations away from the average since instrumental records began 140 years ago) that analysis shows that most of the risk of that event is almost certainly due to the increase in greenhouse gases (Stott P.A. et al 2004, *Nature* **427**, 332-6). It therefore does provide evidence that human induced climate change is occurring.

Regarding the increased storminess of the 1980s and 1990s relative to the 1950s, this has been studied by insurance companies. They report an increase during this period in the number of weather of weather related disasters by a factor of 5 and in the economic cost (adjusted for inflation) of such disasters of a factor of 10. Although part of these observed upward trends is related to socio-economic factors (population growth, increased vulnerability and increased wealth) a substantial part is also linked to the increased frequency and intensity of such events (*Climate Change 2001: the Synthesis Report,* IPCC 2001).

This increased trend in the frequency and intensity of such events is what is expected in a world that is warming due to increased greenhouse gases. As I explained briefly in my written testimony, there are scientific reasons for this trend and further it appears as a robust result from climate models.

## QUESTION 7

There are a number of astrophysicists and other scientists who believe that sunspots are a major contributor to changing temperatures. A recent survey showed at least 100 such studies are underway. Why don't scientists put as much emphasis on this possibility or other aspects of natural climate variability as they do on emissions from human activity?

## ANSWER

The IPCC in its reports has considered all aspects of natural variability as well as the effect of greenhouse gas emissions from human activity. A substantial section of chapter 6 of the IPCC 2001 Report, *Climate Change: the Scientific Basis* is devoted to possible solar influences on climate and about 50 papers on the subject are cited. It remains a subject of serious scientific research interest.

The IPCC's task, however, has been to compare all known natural influences on climate (including solar influences) with the effects of increasing greenhouse gases. Measurements of solar irradiance have been made since 1979 from satellite mounted instruments. Small changes of about 0.1% occur associated with the 11 year sunspot cycle. There is some evidence for solar influence on climate over the last few centuries, for instance during the first few decades of the 20$^{th}$ century. But the influence is small. Over the last 50 years, radiative forcing due to changes in solar irradiance is much smaller than that due to anthropogenic increases in greenhouse gases (see also J. Hansen et al, *Earth's Energy Imbalance: Confirmation and Implications*, in Sciencexpress for 2 May 2005, doi 1110252)

## QUESTION 8

Much of the discussion about climate science being settled is based on the summary chapter of the Intergovernmental Panel on Climate Change of the United Nations. The chapter made specific predictions about the pace of rising temperatures and the relative importance of human activities to climate change. And yet, the body of the report is much more ambiguous and inconclusive about the current state of the science. Is anything being done to ensure that the summary of the next IPCC report is more reflective of the overall analysis by the scientists?

## ANSWER

I am aware that statements are often made and quoted asserting that the Summaries for Policymakers (SPM) of the IPCC reports do not accurately reflect the science of the underlying chapters. Yet, to my knowledge, none of those expressing such views have provided evidence or examples to support them.

It is important to recognize the IPCC's purpose in preparing an SPM for its reports. As an intergovernmental body, the IPCC is bound to produce its conclusions succinctly and in a form that is understandable by policymakers and relevant and helpful to their needs. The SPM therefore is not a scientific summary of all the science laid out in the chapters. It does not list, for instance, all the factors or all the arguments involved in the scientific appraisal of any given area. Each chapter, in any case, produces its own scientific summary. The SPM is a summary of conclusions, largely taken from the chapter summaries, selected for their policy relevance and in the drafting of which lead authors from the chapters have played a full part.

It is also important, as your question implies, that the SPM adequately expresses the degree of certainty to be associated with any conclusion. The IPCC has spent a lot of time debating how this can best be done and a large proportion of the time in the intergovernmental meetings that have approved the SPMs (see also my answer to Q11 asked by Senator Bingaman) has been taken up with ensuring that the final SPM text accurately reflects the chapters in the degree of confidence expressed in the conclusions. When this has to be done succinctly, as the SPM requires, it is helpful for confidence to be expressed quantitatively. For instance, in all the IPCC scientific reports, so far as possible, numerical values quoted in the conclusions also included error bars to express their uncertainty. In addition, in the 2001 IPCC Report, many of the more qualitative statements have been made quantitative by attaching to them numerical estimates of probability. For instance, a given conclusion described as *likely* is estimated to have a probability of being true in the range 67% to 90% and as *very likely* when its probability of being true is estimated as in the range 90% to 99%, and so on. In this way, uncertainties have been presented in a manner that can be more easily interpreted and used by policymakers, especially when the impacts of climate change have to be folded into the consideration of wider policy issues involving future energy generation or the provision of security.

Further, in the IPCC 2001 SPM, clearly listed are areas of importance where there is no evidence of change, for instance in sea ice cover in the Antarctic or in the average number and intensity of tropical cyclones over the 20$^{th}$ century.

I have no doubt at all that matters regarding the accuracy and balance of the SPM and the way uncertainties are represented continue to be very fully discussed within the IPCC as it prepares the Fourth Assessment Report.

## QUESTION 9

The natural "greenhouse effect" has been known for nearly two hundred years and is essential to the provision of our current climate. There is significant research in the literature today that indicates humans, since the beginning of their existence, have caused an increase in the greenhouse effect. Some argue that the development of agriculture 6,000 to 8,000 years ago has helped to forestall the next ice age. The development of cities, thinning of forests, population growth, and most recently the burning of fossil fuels, have all had an impact on climate change. Our ecosystems have constantly adapted to change, as we as humans have adapted to our ecosystems as well. Is it possible that the increased presence of CO2 caused by the 8,000 years of modern human existence may be something our ecosystems will continue, as they previously have, to naturally adapt to?

## ANSWER

According to data from the Vostok and Taylor Dome ice cores, atmospheric $CO_2$ concentration rose by 20ppm

(from 260ppm to 280ppm) between 8,000 years ago and the start of the industrial era (circa 1750). Since then, $CO_2$ has risen to 377ppm in the Mauna Loa record. This is higher than at any time in the 440,000 year ice core record and also higher than at any time in the last 20 million years according to geochemical evidence. There are therefore no examples in the recent past to which we can refer for evidence of adaptation to current or projected future $CO_2$ levels.

The amount of the $CO_2$ rise over the last 250 years has been nearly 5 times that seen over the previous 8,000 years, with the rate of rise 150 times faster. Ecosystems will already need to be adapting more rapidly than before. In the six illustrative SRES scenarios examined in the IPCC Third Assessment Report of 2001, the $CO_2$ concentration reaches between 540ppm and 970ppm over the next 100 years. These correspond to rates of rise of 650 to 2300 times faster than over the 8,000 years pre-industrial. Adapting to the associated climate change under any of these scenarios will become increasingly difficult for both ecosystems and humans.

## QUESTION 10

The panel touched on some energy alternatives such as biomass, natural gas, and nuclear power, yet there was little mention of hydrogen power. From a scientific viewpoint, where do you think we are on being able to really utilize hydrogen power? What is the potential of hydrogen power?

## ANSWER

Hydrogen has many advantages as a fuel in that it is very non-polluting and is ideal for using in fuel cells that are potentially highly efficient and convenient devices for producing electricity. Further, providing the hydrogen is produced from a carbon-free source, it does not add to the greenhouse effect.

Hydrogen power does not, however, exist in isolation from the means by which the hydrogen is produced. That may be from solar energy or from the energy alternatives that you have mentioned such as biomass, natural gas or nuclear sources. Hydrogen essentially provides a secondary rather than a primary source of energy.

There seems to be general recognition that hydrogen has great potential and will become an important and probably dominant fuel in the future. Before this occurs on a very large scale, substantial further development of fuel cells and of technologies for hydrogen storage are required especially for use in vehicles.

## QUESTION 11

The panel established very clearly that we should adopt policies that decrease carbon emissions regardless of any other carbon emissions policies we pursue. We are currently or will shortly be providing expanded incentives for clean coal, nuclear energy and renewable fuels. Do you feel this is money well spent? What technologies do you feel the government should be more involved in developing?

## ANSWER

I am not an expert on energy policy so can only make a general comment. It is clear, I believe, that there is no one solution to the challenge of moving to carbon free energy, so all possibilities need to be explored and assessed. There are also comparatively new technologies, especially some in the field of renewables, that will require considerable government support before they can become commercially competitive.

# Questions for the Record
# Senator Talent

## QUESTION 1

There has been a fair amount of criticism of the output of the models used to forecast possible climate conditions in the future, due in part to the data assumptions made. How responsive has the IPCC been to external criticism? Has this criticism led to any modeling or data input revisions, and what was the result of these revisions?

## ANSWER

In contrast to models of the economy, for example, climate models are not based on empirical or statistical

extrapolation but they possess a sound theoretical basis in the established laws of physics and dynamics. These include the laws of conservation of mass, heat, moisture and momentum and the equation of state. Future projections are determined through integration of the equations describing these laws together with Newton's equations of motion. Such models are essential tools for adding together all the non linear processes involved in the behaviour of the total climate system. A good description of the present state of climate modeling can be found in J.F.B.Mitchell, Can we believe predictions of climate change*? Q.J.R.Meteorol.Soc.,* **130,** 2341-2360, 2004.

There has been enormous development in the size, sophistication and skill of climate models over the last 30 years. The global modeling community has been closely involved in the IPCC process and contributed a great deal to it. In particular, for the 2001 IPCC Report, 20 groups in different institutions and countries running over 30 general circulation models with full coupling between the atmospheric and ocean circulations set up elaborate procedures to evaluate and compare formulations and results between all 30 models. This process has been highly productive in leading to improvements in model performance, creating increasing confidence in model results and providing guidance for model developments.

Many of the criticisms of models commonly voiced concern older models in some of which adjustments (e.g. flux adjustments at the atmosphere-ocean boundary) had to be made the validity of which was questioned. The modeling community has worked to remove such limitations. For instance, modern models do not require flux adjustments. The main uncertainties in models that remain arise from difficulties of adequately dealing with clouds and with the ways in which small scale motions (too small for discrete model description) influence motions on the larger scale. Uncertainty about clouds is the main reason for the range of uncertainty from 1.5 to 4.5 ° C still quoted by the IPCC for the climate sensitivity (the increase in equilibrium surface temperature arising from a doubling of carbon dioxide).

## QUESTION 2

You say in your written testimony (p. 7) that the Kyoto Protocol is just a "beginning for the process of reduction" for countries that ratified the protocol. What level of cuts are necessary to reach the goal of Kyoto? If the EU is having trouble meeting the "beginning" targets, how will they meet the necessary targets without wrecking their economies, and how are the rising emissions of developing countries factored in?

## ANSWER

I have consulted with the UK government in providing this answer. The goal of the Climate Convention is to stabilise greenhouse gases in the atmosphere at levels which avoid dangerous anthropogenic climate change. The European Union (EU) has suggested that this would mean avoiding temperature rises greater than 2 degrees Celsius above pre-industrial levels. Recent research indicates that to do so requires global greenhouse gas emissions to peak within the next two decades, followed by substantial global reductions relative to 1990. These would need to be of the order of at least 15% and perhaps as much as 50% by 2050. Developed countries would need to take greater action which suggests that their emissions will need to fall by between 60 and 80% of current levels by 2050. Kyoto is thus clearly just a first step as its goal is to achieve reductions in developed country emissions in the near term (2008 to 2012). However the Protocol includes built in mechanisms for considering what actions should be taken by parties in the period after 2012 and initial discussions on this are due to begin among Kyoto parties at the 1st meeting of the Parties to the Kyoto Protocol, this November in Montreal.

With regard to the EU's Kyoto targets, a recent European Commission report (http://europa.eu.int/eur-lex/lex/LexUriServ/site/en/com/2004/com2004_0818en01.pdf) suggests that a combination of existing domestic policies and measures, additional policies and measures which are already in an advanced state of planning, and emission credits gained through the Kyoto Protocol's project-based mechanisms will deliver a total EU-15 emissions cut of 8.6% by 2010 (the EU-15 target is -8%). The EU Council of Ministers has set out a range of emission reduction pathways, as noted above, to consider when discussing the future with other parties. The UK aims to use its Presidency of the EU to launch the process of developing strategies or pathways to deliver those kinds of medium and long term targets. The UK hopes to introduce in the EU the same kind of process taken by the UK in 2003 when it formulated its Energy White Paper, undertaking the necessary work to demonstrate that future targets adopted are achievable and compatible with healthy economic growth.

## QUESTION 3

You note in your written testimony (p. 8) that for the UK to meet its target of 60% reductions by 2050, it would suffer a loss of 6 months' growth over 50 years, or 1% of the growth over that time period. How much money in GDP and how many lost jobs does that represent? Does this result in any reduction in emissions, particularly in light of the fact, as you note, that China is building the equivalent of a 1 gigawatt, fossil-fuel powered generating station every week?

## ANSWER

I have consulted with the UK government in providing this answer. Analysis for the UK's Energy White Paper in 2003 concluded that the costs of achieving a 60% reduction in $CO_2$ emissions might be around 0.5-1% of GDP in 2050. This would be broadly equivalent to a reduction of about 0.01 percentage points a year in the assumed GDP growth rate of 2.25% a year. The cost to GDP in 2050 is estimated to be between £10bn and £25bn per annum (in 2000 prices) by 2050 compared with a forecast level of GDP in 2050 of around £2500bn. There are no figures available for the effect on employment. If the UK achieves a 60% reduction in its carbon dioxide emissions this would mean that the UK's annual emissions had fallen to around 65 million tonnes of carbon by 2050, about 90 million tonnes lower than they are currently. To put this in context, a new 1 GW coal-fired power station might be expected to emit around 1.5 million tonnes of carbon per year. The Energy White Paper recognises that it won't be enough for the UK to act alone and that others will need to make comparable efforts to meet the challenge of climate change.

## QUESTION 4

The time for greenhouse gas emissions in the atmosphere to decay, as predicted by the IGCC model is about 37 months. However, actual experience based on studies of volcano eruptions suggest a decay time of half of that (Michaels and Knappenberger, 2000) or less (Douglass and Knox, Univ. of Rochester, reported in *Geophysical Research Letters*), meaning a lower climate sensitivity and lower the future temperature rise. Have the IGCC numbers been rerun to account for this actual data, rather than sticking to the modeling assumptions?

## ANSWER

Different greenhouse gases have different lifetimes in the atmosphere. The fundamentals of their atmospheric cycles and lifetimes are well understood. I do not recognize to what decay the 37 months refers. However, I believe the Senator's question is rather about the transient climate response observed after the Pinatubo volcanic eruption and how this might be used to constrain our knowledge of climate sensitivity and "global warming commitment" (the extra-warming in the pipeline once greenhouse gas concentrations have been stabilized). The climate response to stratospheric aerosols induced by the Pinatubo eruption has been used in a number of studies to attempt to provide information about climate sensitivity or the time constant of climate response to perturbations in radiative forcing such as occurs with greenhouse gases. The one you cite by Douglass and Knox essentially employs an extremely simplistic one-dimensional model that includes no allowance for the ocean and also employs an incorrect definition of radiative forcing. Other studies have used full three-dimensional climate models (Kircher et al, Journal of Geophysical Research, 104, 19039-19055, 1999; Soden et al., Science, 296, 727-730, 2002) and find that moderate to high climate sensitivities (i.e. 3 to 4.5 degrees C for a doubling of $CO_2$ at equilibrium) are compatible with the observations. However, as pointed out by R.S.Lindzen and C. Giannitsis (J. Geophys. Res.,. 103, 5929-5941, 1998) in a detailed study on the climatic effects of volcanic cooling, the uncertainties associated with the climate response are such that no clear conclusions can be drawn regarding either climate sensitivity or the time scale of climate response from studies on a single volcanic eruption such as Pinatubo.

## QUESTION 5

What has been the pattern of findings as the science improves – more or less climate sensitivity to carbon concentration in the atmosphere, greater or lesser projected warming? E.g., I understand that the large majority of models predict a more modest warming of 2-5 degrees F, as opposed to IGCC's Third Assessment Report which predicts about 11 degrees F (6 degrees C) by 2100.

## ANSWER

The IPCC's Third Assessment Report in fact gave an uncertainty range of 1.4 to 5.8 degrees C (2.5 to 10.5 ºF) for the projected global average temperature rise in 2100 – you just mention the top end of that range. Included in that range are uncertainties in projections of how greenhouse gases will increase in the 21st century (that is dependent on how emissions due to human activities evolve) in addition to uncertainties in our scientific understanding of the response of climate to increased greenhouse gases. The range for global average temperature rise projected for 2100 published in the IPCC 1995 Report of 1.0 to 3.5 ºC (1.8 to 6.3 ºF) was less than that in 2001, largely because of different assumptions about likely emissions of aerosols due to human activities and also of greenhouse gases, in the 21st century.

The response of climate to increased greenhouse gases is described by a quantity called the *climate sensitivity* that is defined as the amount of global average temperature increase for a doubling of atmospheric carbon dioxide concentration under equilibrium conditions. This is a quantity determined from the science. Your question, I believe, is asking how estimates of the *climate sensitivity* have changed as our understanding of the science has improved.

In both the First and Second IPCC assessment reports of 1990 and 1995, the range of estimates of climate sensitivity was 1.5 to 4.5 ºC (2.7 to 8.1 ºF). In the IPCC Third Assessment Report (TAR) of 2001, the conclusion drawn in the summary section of chapter 9 was that "the previous estimated range for this quantity, widely cited as +1.5 to +4.5 degC, still encompasses the more recent model sensitivity results". However, in Table 9.4 of that chapter, the range of values of climate sensitivity in the 15 full climate models available to that chapter was quoted as from 2.0 to 5.1 ºC (3.6 to 9.2 ºF) with a mean of 3.5 ºC (6.3 ºF), indicating a tendency for models at that time to show somewhat higher values of climate sensitivity. Since the publication of the TAR there have been a number of studies in which models have produced climate sensitivities in excess of 6 ºC (11 ºF) (e.g. Murphy et al., 2004, Nature, **430**, 768-772; Stainforth et al., 2005, Nature, **433**, 403-406). In general, the lower end of the uncertainty range for climate sensitivity has tended to remain at 1.5-2 ºC (2.7-3.6 ºF) while the upper range has increased.

In conclusion, therefore, as the science has developed and improved, there has been a tendency for an increase in the likelihood of greater sensitivity and greater warming.

## QUESTION 6

What's the status of the review of the Mann "hockey stick" temperature curve? I understand that studies by Stephen McIntyre and Ross McKitrick suggest that it relied on the statistically insignificant bristlecone pine. Is the IPCC taking another look at that work, which forms the basis for much of today's climate change debate?

## ANSWER

I have received a similar question from Senator Bingaman(Q8c). I provide the same reply to both questions

This is a fast moving area of research. Very recently the assertions by McIntyre and McKitrick (2005a, b) (MM), alluded to in the question (references at end of answer), have been shown by several papers to be largely false in the context of the actual data used by Mann and co-workers. Ammann (a palaeontologist at the National Centre for Atmospheric Research) and Wahl of Alfred University have two papers, one in review and one in press, that reproduce the original results published by Mann et al in Nature in 1998 and Geophysical Research Letters, 1999 and prominently used in the IPCC Third Assessment Report. They demonstrate that the results of MM are due to MM having censored key proxy data from the original Mann et al (1998) data set, and to having made errors in their implementation of the Mann et al method. They specifically show that fifteenth century temperatures, related to the bristlecone pine issue, were not similar to twentieth century temperatures, as was suggested by MM. Amman and Wahl issued a press release in May 2005 on this finding. Fuller details are at
http://www.ucar.edu/news/releases/2005/ammann.shtml
These authors state that they will make their full computer code available publicly.

A specific claim is made by MM that the "hockey stick" shape of the Mann et al reconstructions is derived from the way Mann et al normalise and centre their principal component pattern data. This has recently been tested. Rutherford et al (in press, Journal of Climate) have shown that essentially the same result as Mann et al is obtained using an entirely independent statistical method on similar data. This eliminates the step of representing regional tree-ring networks by principal components. The likely reason why Mann et al were able to successfully use their particular technique is because the structure of paleoclimate data is more complex than the temporal "red noise"

tested by MM.

Other investigators have reconstructed climate over the past 1000 years using very different techniques and different selections of data. Some of these results are recent, and some were shown in Fig 2.21 of the IPCC Third Assessment Science Report, Climate Change 2001. These authors tend to find a greater magnitude of climate variability than did the Mann et al "hockey stick" results. In particular the "Little Ice age" centred around 1700 is generally cooler. Some of the more recent papers of this type show a Little Ice Age cooler by up to several tenths of a degree centigrade than any reconstruction shown in the Third Assessment Report in Fig 2.21, including that of Mann et al. However, all but one recent papers (Esper et al, 2002, Mann & Jones, 2003, Moberg et 2005, Huang, 2004, Jones & Mann, 2004, Bradley et al ,2003) find that the warmth of the late 20th century is still exceptional, as their reconstructions of the temperature level relative to the 20th century in the Medieval warm period are similar to the Mann et al results. Soon & Baliunas concluded that the late 20th century was not unusually warm but their methodology was flawed (Mann and Jones, 2003) as they equated hydrological influences with temperature influences and assumed that regional warmth corresponded to hemispheric warmth.

I am sure that the IPCC Fourth Assessment Report will fully take all these new findings into account. In the meantime, it is important to recognise that no evidence has emerged that seriously calls into question findings regarding the climate of the 20th century and the influence of human activities as described in the IPCC 2001 Report.

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## QUESTION 7

If all the countries that have signed Kyoto stay within compliance of Kyoto, how much of a reduction in global warming would this result in?

## ANSWER

I have consulted with the UK government in providing this answer. If the developed country parties make the reductions they have committed to, in the period 2008-2012 the reduction in projected global emissions will be up to about 2%. This takes account of the fact that developing country emissions will still rise as they do not have emission reduction targets, although mechanisms such as the clean development mechanism, together with technology transfer and capacity building, will be expected to lead to some reduction in their emissions growth. The significance of the first commitment period is as a first step for building broader coalitions and a longer-term engagement aimed at reducing global emissions of greenhouse gases, as well as the establishment of essential

monitoring and measuring standards and cost-effective market mechanisms such as international emissions trading.

## QUESTION 8

Can you confirm that suspended water vapor levels, cloud cover percentages and direct solar irradiation changes over time all represent variables in these forecasting models that could have significant impacts on the conclusions of the results of these models?

## ANSWER

In the formulation of climate models, estimates of direct solar radiation changes with time are included, along with estimates of all other known forcing factors, both natural and anthropogenic. There are periods such as that from around 1900-1940 when it is believed solar radiation changes had a significant effect. Any effect of solar radiation changes over the last 50 years, however, has been small compared with the effects of increasing anthropogenic greenhouse gas emissions *Climate Change; the Scientific Basis*, the IPCC 2001 Report, chapter 6).

Water vapor concentration and the coverage of cloud (at different levels and of different types) are variables within the model equations that are generated within the model as the model integrations progress by applying the physical laws on which the model depends. These variables are not introduced from outside except in the specification of initial conditions; the influence of the these is soon lost as the integrations progress. The way in which clouds are treated within the model equations differs significantly amongst models. The largest single uncertainty in model results arises from uncertainties regarding this treatment as is explained in *Climate Change; the Scientific Basis*, the IPCC 2001 Report, chapter 8.

## QUESTION 9

In looking at pre-industrial global temperature patterns, would you agree that changes in temperatures over time have occurred that had no anthropogenic basis?

## ANSWER

Temperature is a climate variable that has large natural variability over all time scales and space scales. The natural variability can arise because of external forcing such as changes in solar radiation or because of variations within the climate system itself. In addition to this natural variability, changes occur because of human activities, for instance deforestation, changes in vegetation or land use and since the industrial revolution because of changes in atmospheric composition especially most recently emissions into the atmosphere of growing quantities of greenhouse gases.

The task of the IPCC has been to study thoroughly all reasons for climate variability and change both natural and anthropogenic and, through appropriate scientific analysis and the employment of climate models, to distinguish as far as possible between natural and anthropogenic effects.

## QUESTION 10

Do we know what the "best" global temperature is to sustain life?

## ANSWER

Life of all kinds - human and non human - exists successfully on earth under a very wide variety of climates. What is important to realize is that humans and ecosytems have over millennia and centuries adapted to reasonably stable local climatic conditions. But unusually large climate changes are beginning to occur on a global scale and at a rate that is greater than for at least 10,000 years. If the local climate changes too rapidly, adaptation to new conditions may be difficult for both ecosystems and humans. The IPCC has concluded, *'Projected climate change will have beneficial and adverse effects on both environmental and socio-economic systems, but the larger the changes and rate of change in climate, the more the adverse effects predominate'* (Climate Change 2001, Synthesis Report,

Many ecosytems are sensitive to unusual and sustained changes in temperature or precipitation. I give two examples. First, many areas of tropical corals are suffering 'bleaching' because of increases in ocean temperature. Corals are also expected to be seriously affected by the increased ocean acidity that is occurring because of carbon dioxide from anthropogenic sources that is emitted into the atmosphere and then dissolved in ocean waters – an

environmental problem that has only recently been appreciated. (see UK Royal Society Report 12/05, *Ocean acidification due to increasing atmospheric carbon dioxide*, 30 June 2005, available on <www.royalsoc.ac.uk>). A second example is of substantial die back that is occurring in forests at northern high latitudes because of increased warming outside their normal range of tolerance.

Over past epochs humans have responded to severe local or regional climate changes by moving into other more tolerable areas. In our modern extremely crowded world large population movements are no longer possible. To some adverse changes, it will be possible for humans to adapt, although often at significant cost. For instance, adaptation to changes in average water availability, average temperatures or some sea level rise might be achieved through alterations to water resource infrastructure, building design or sea defences. For many low lying areas, however, such as large populated deltas or many islands, adaptation to sea level rise is not a practical possibility and many millions will be displaced. Further, the increases that are likely in the frequency and intensity of floods and droughts will cause large problems especially for populations in sub tropical countries that are particularly vulnerable to such events.

## QUESTION 11

What is currently being done to curb emissions from parts of the world in poverty who are deforesting their environment and burning biomass for all means of day-to-day living, and are these emissions continuing to increase in the world?

## ANSWER

*Are these emissions continuing to increase*

Deforestation releases $CO_2$ to the atmosphere both from the vegetation directly and also by disturbing the soil. The numbers quoted below refer to this. Burning biomass as a day-to-day fuel leads to net $CO_2$ emissions if the biomass is not replaced. If the biomass is grown explicitly for fuel wood then there are no net $CO_2$ emissions as the carbon biomass stock on average remains constant.

CO2 flux from land-use change is increasing at about the same rate as fossil fuel usage. On a global scale, in 1980 land-use change accounted for about 23% of total anthropogenic emissions and in 2000 about 24%. Regionally, there are some differences. From 1980 to 2000, land-use carbon fluxes increased by 30% in tropical America - close to the global average increase. Larger increases occurred in tropical Asia (56%) and tropical Africa (60%).

(Data taken from: Houghton, R.A., and J.L. Hackler, 2002. *Carbon Flux to the Atmosphere from Land-Use Changes*; and Marland, G. et al, 2005, *Global, Regional, and National CO2 Emissions* – both in Trends: A Compendium of Data on Global Change, Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A. Both are available at: http://cdiac.esd.ornl.gov/trends/trends.htm

*What is currently being done*

My main personal experience of this problem comes through the Shell Foundation (a large charity set up by the Shell Company mainly to support sustainable energy provision in the third world) of which I am a Trustee. The Foundation has a large program aimed at the creation of local enterprises that build and market simple efficient stoves using traditional fuels that will substantially the reduce the amount of fuel that is used and also reduce indoor air pollution with the serious damage to health that it causes. The Foundation also has programs aimed at the creation of enterprises to provide sustainable and affordable energy to poor communities often from the use of readily available waste material (e.g. rice straw in China, coconut shells in the Philippines etc). The potential for the multiplication of such projects is very large. An aim of the Foundation is to join with other bodies and agencies to create mechanisms for the large scale-up of such programs so that they can become significant on a global scale both in the provision of energy to poor communities and also in reducing greenhouse gas emissions.

## QUESTION 12

Do you believe it is practical to seek emission controls in parts of the world that are struggling in poverty?

## ANSWER

I believe the top priority is to achieve emissions reductions in the parts of the world that are making the largest emissions contributions i.e the industrialized nations and those nations that are rapidly industrializing. Regarding nations 'struggling in poverty', as you will see from my answer to Q 11, I believe there is great opportunity for agencies and governments in the developed world to assist them to move out of poverty in ways that are sustainable and that reduce rather than increase their greenhouse gas emissions.

## QUESTION 13

What is being done to curb emissions in the developing countries like China and India?

## ANSWER

In reply to Question 3 from Senator Bunning, I emphasized the importance of developed countries leading by example with regard to developing countries such as China and India. I also mentioned the responsibility on developed countries to develop partnerships with countries that are seeking to industrialize so as to assist them in whatever ways they can with the development of low carbon or carbon free energy generation. Further, it is essential that developing countries are full participants in agreements that need to be reached regarding targets and mechanisms in the next stage of negotiations that is taking place within the FCCC.

# Questions for the Record
# Senator Feinstein

## QUESTION 1

Is there any credible scenario for stabilizing greenhouse gas emissions that does not involve the United States and other major emitters stopping their emissions growth over the next couple of decades and sharply reversing their emissions growth by 2050?

## ANSWER

All scenarios of global emissions that stabilize carbon dioxide concentrations in the atmosphere this century slow emissions growth over the next few decades and reverse that growth severely during the second half of the century. That applies to *global* emissions. The slowing and reversal of emissions for industrialized countries need to occur more quickly than for global emissions so as to allow room for growing industrialization in developing countries. I provide examples of stabilization profiles for both developed and developing countries in my written testimony to the committee.

## QUESTION 2

Would the National Commission on Energy Policy's proposal stop and then reverse U.S. greenhouse gas emissions?

## ANSWER

I am not an expert on energy policy and cannot comment in detail on the proposals of the National Commission on Energy Policy. As I understand it, their main proposals are limited to stopping the growth of emissions by 2020 and do not cover the period after that date, although they recognize in their report the need for the reversal of emissions growth after 2020.