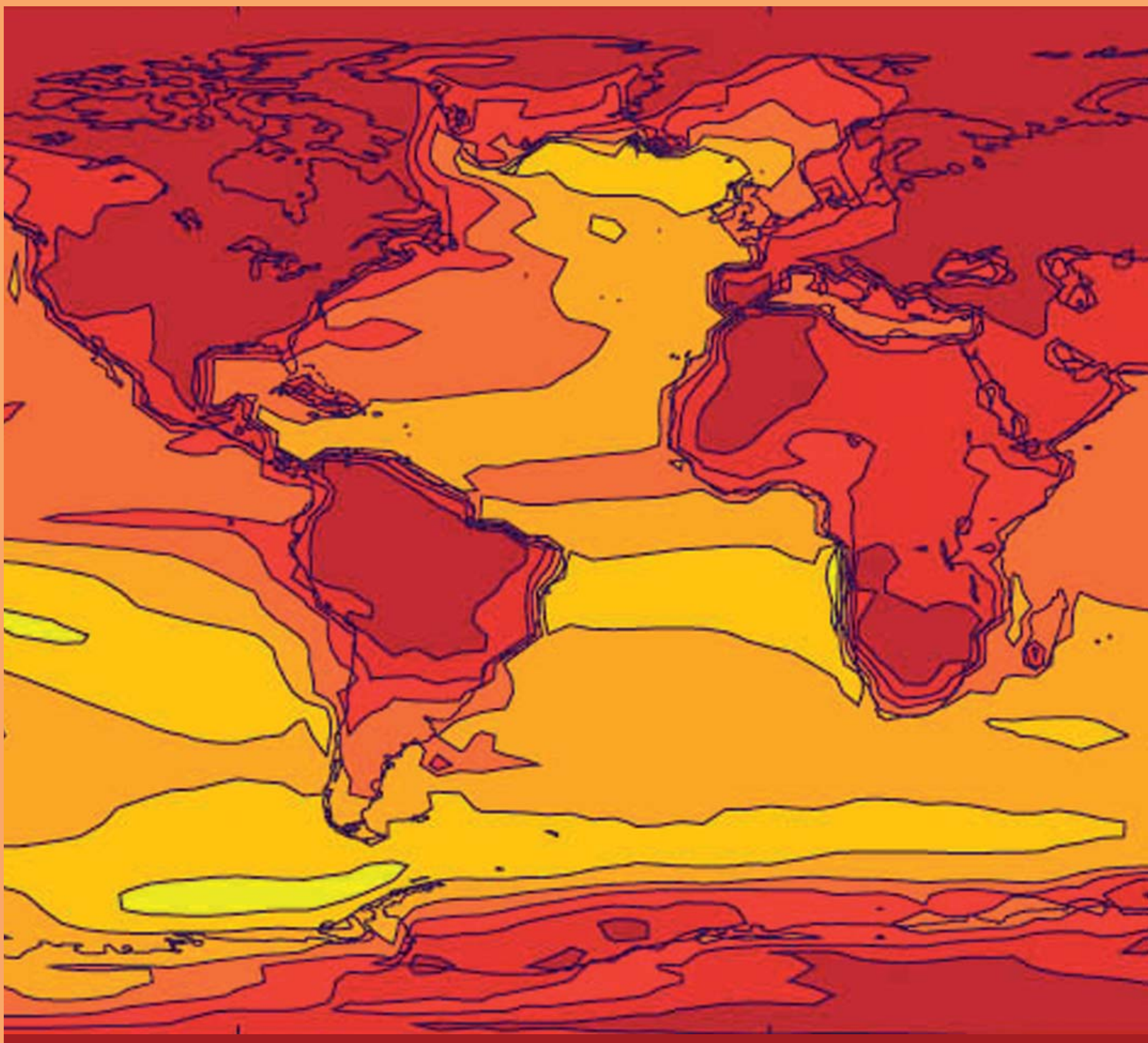
Climate change prediction: a robust or flawed process?



A seminar organised by the Institute of Physics

The Institute of Physics held a seminar on 7 June 2007 to discuss the validity of current strategies, in particular computer models used to predict climate change, to establish and evaluate the link between global warming and human activity.

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Introduction

One of the major concerns today is the rise in global temperatures, which are generally thought to be caused by the release of anthropogenic greenhouse gases. As a result, a growing proportion of the political agenda is occupied by the challenge of implementing policies and strategies in time to mitigate the possible consequences of global warming.

A key element in assessing climate change is the powerful computer simulations used to demonstrate how complex, interacting forcing agents influence the evolution of the climate system. Although the models are built around a long-accumulated understanding of the underlying physical processes and dynamics – and are compared with historical and contemporary observations – there are still many aspects that are less well understood. There is, therefore, a range of views about the reliability of using these models to make credible projections of our future climate.

At the seminar, two leading climate physicists, **Prof. Richard S Lindzen**, Alfred P Sloan Professor of Meteorology at the Massachusetts Institute of Technology (MIT), and **Prof. Alan J Thorpe**, chief executive of the Natural Environment Research Council (NERC), described the current status of climate-model prediction from rather different viewpoints. Prof. Lindzen explained the limitations of climate models and outlined why attempts to attribute global temperature rise to an increase in carbon dioxide (CO_2) emissions were flawed. He maintained that there was no sound evidence that temperatures would rise substantially in the future. Prof. Thorpe based his presentation on the huge weight of evidence in the scientific literature, showing that current and future warming of the climate is caused by the human input of greenhouse gases. He presented a variety of evidence supporting the validity of current global models on which current concerns about global warming are based. He also stressed that more research was being done and needed to refine the details further.

The seminar was chaired by **Michael Meacher**, MP for Oldham West and Royton, and a former Minister of State for the Environment. **Prof. Chris Rapley** of the British Antarctic Survey and **Piers Corbyn** of WeatherAction joined the speakers in answering questions from the audience.

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The seminar

The past few years have seen a substantial increase in concern about the potential effects of greenhouse emissions on our climate. The debate has spread and intensified as ever more reports of geophysical changes, such as melting ice sheets and "extreme weather", are presented in the media as evidence for global warming.

This concern is given substantial scientific support by reports from the United Nations Intergovernmental Panel on Climate Change (IPCC),[1] which are based on a large body of evidence from thousands of projects, programmes and papers. The latest (Fourth Assessment) IPCC *Summary for Policymakers, Working Group I*,[2] states: "Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level." It concludes: "Most of the observed increase in global average temperatures since the mid-20th century is *very likely* (i.e. 95% likely) due to the observed increase in anthropogenic greenhouse gas concentrations." Furthermore, according to the IPCC Working Group III report *Mitigation of Climate Change*,[3] global greenhouse gas emissions have grown by 70% between 1970 and 2004, and will continue to grow over the coming decades, possibly doubling by 2030.

Unreliable models

Richard Lindzen is, however, concerned that such statements give credence to misleading projections of future catastrophe. Attribution is problematic, he says, because the underlying chain of causes and effects is long, and based on rather tenuous inferences. The chain starts with CO_2 emissions, leading to increased atmospheric CO_2, which then results in so-called radiative forcing, whereby infrared radiation – which normally balances net incoming solar radiation (the incoming solar radiation minus the part reflected) – is now emitted from a higher, colder level where it no longer balances the net incoming solar radiation. The difference is what is referred to as radiative forcing. Prof. Lindzen noted that this is both different and more accurate than the popular image of greenhouse gases trapping heat (figure 1). While these links are relatively easy to calculate, determining the global response to radiative forcing is much less straightforward. Moreover, these are merely the links leading to global mean temperature. The links leading to the impacts of global mean temperature are far longer and more tenuous.

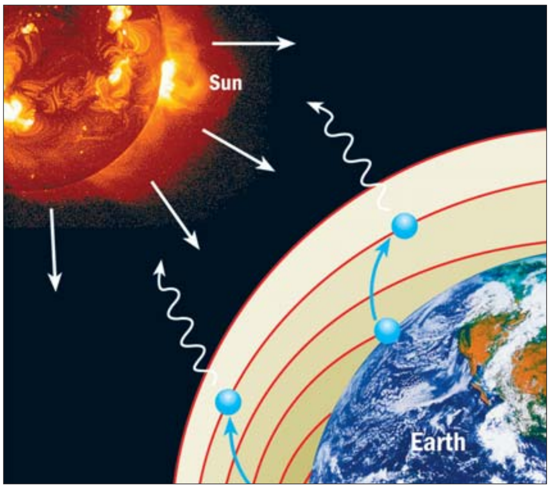

Figure 1: The real greenhouse effect. The surface is not cooled by the emission of radiation, largely because the infrared opacity of water vapour is too great. This is highest at the ground over the tropics and diminishes polewards and upwards. Air currents carry heat to regions of diminished infrared opacity – to the middle of the troposphere, from where it is radiated into space – balancing the absorbed sunlight. It is the warming at these levels that is fundamental to the real climate greenhouse effect. Lighter shading represents reduced opacity due to diminishing water vapour density.

The approach taken has been to develop a computer description of the climate system based on the underlying processes – the chemistry of the atmosphere, radiative transfer of heat, and fluid dynamics. However, the equations associated with turbulent fluid flow are notoriously difficult to solve and have to be done numerically on computers. The numerical solutions are inevitably different from the solutions of the underlying equations. Prof. Lindzen pointed out that while such models are useful for a variety of purposes, their limited resolution and other shortcomings make it very difficult for them to establish the effects of unresolved feedback factors, such as clouds, even though they play an essential role in the global and local response to radiative forcing. The shortcomings of models are frequently disguised in simulations where there are many adjustable parameters in the computer models that can be "tuned" to fit the available observational data, making the models unreliable as a prediction tool.

An alternative approach

Prof. Lindzen went on to suggest an alternative approach that could provide a better insight into the link between CO_2 levels and temperature. It starts with an analysis of the basic physics of the greenhouse effect. In nature, heat absorption by greenhouse gases (primarily water vapour) is so effective as to render the cooling of the Earth's

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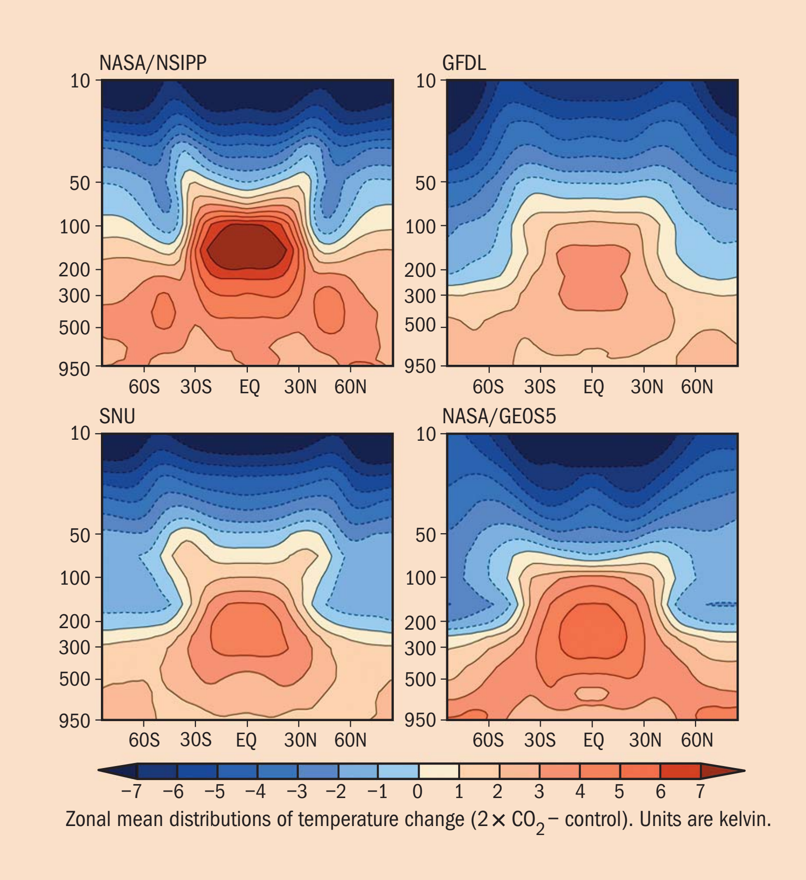

Figure 2: Recent results for four state-of-the-art computer models for a doubling of CO_2.

surface by radiation very inefficient. Thus the surface is cooled mostly by motions associated with convections, storms and so on, which carry heat (in the form of both heat and the latent heat of moisture) to levels higher in the atmosphere from which heat can efficiently be radiated to space. The radiation from these levels is roughly proportional to the fourth power of the absolute temperature at these levels and it is this radiation that balances the net incoming solar radiation. When greenhouse gases are added to the atmosphere, this level is increased and, because the temperature of the troposphere decreases with height (at a rate of about 6.5 °C/km), the radiation from the new level is diminished. To re-establish balance with net incoming solar radiation, the temperature at the new emission level must increase. This is the essential warming associated with the greenhouse effect but its relation to warming at the surface is unclear. Determining this relation is something that computer models are actually likely to be good at.

Recently, a collaboration between Princeton University, NASA and the University of Seoul in Korea[4] studied four models whose sensitivity to a doubling of CO_2 ranged between about 1.5 and 3.5 °C (figure 2). Despite the widely varying sensitivities in each of these models, the maximum warming occurred in the tropical upper troposphere (near the emission levels) where it was approximately 2.5 times the average warming of the surface. Surface-warming rates since 1979 are generally held to have been about 0.13 °C per decade.

Balloon data analysed by the Met Office Hadley Centre in the UK show that, since 1979, the warming rate in the tropical upper troposphere has not been 2.5 times as large as the surface warming but rather has only been about 0.1 °C per decade.[5] Thus, Prof. Lindzen suggested that only about 0.04 °C per decade of the observed surface warming could be attributed to greenhouse warming. This implied a much smaller sensitivity than the models display – in the order of 0.4 °C for a doubling of CO_2 – rather than 1.5 to 4.5 °C found in current models. The remaining warming at the surface could readily be caused by the natural internal variability of the climate system, where the ocean is never in equilibrium with the atmosphere, and where ocean variations happening on timescales from years to millennia serve as sinks and sources of heat for the atmosphere.

Prof. Lindzen noted that, according to the latest *IPCC Summary for Policymakers of the Scientific Assessment*, we are already 86% of the way to the radiative greenhouse forcing associated with the doubling of CO_2, and we have seen a change only of between 0.6 and 0.8 °C in the past 100 years, which would be too small even if all of it were due to anthropogenic greenhouse gases – an unlikely possibility in light of the previous argument. The easiest cause of this low response, he noted, would be that the models have been exaggerating climate sensitivity, though the modelling community maintains instead that aerosols (the properties of which, the IPCC acknowledges, are poorly known) have cancelled much of the greenhouse warming. Prof. Lindzen also noted that some of the warming is delayed in current models by the thermal inertia of the oceans, though there are substantial reasons to suppose that the delay has been exaggerated in current models as well.

He believes that current climate models exaggerate the impact of CO_2 on temperature because of a poor understanding and representation of the feedback effects due to clouds and water vapour. These effects, he suggested, are likely to depend on variations in the areal coverage of cloudy and moist air rather than on the average values of each. Finally, Prof. Lindzen speculated on the surge of activity on behalf of controlling greenhouse emissions that has characterized the past two years. One factor, he suggested, might be that the records of the Hadley Centre, for example, show that there has been no warming trend in global average temperature for the past 10 years.[6] The issue of global warming has been actively promoted for more than 20 years, during which time numerous groups have developed strategies for exploiting the issue. It is possible that if these strategies are not implemented soon they may never be.

Describing the comments of some scientists, Prof. Lindzen noted: "Attributing global warming to the rise in greenhouse gases has been reduced to an issue of religious faith modulated by policy relevance." Pointing out that policy relevance was largely a political matter, he added: "Unfortunately, in my experience when politics enters the picture, science takes a back seat – even among scientists."

The weight of evidence

Alan Thorpe defended the conclusions of the IPCC report based on the weight of evidence published in the scientific literature, refuting Prof. Lindzen's claims that the models were unreliable. The models incorporate well established laws of physics, and the evolution of temperature is one of the model outputs. Model simulations do not involve arbitrary chains of inference – processes interact with each other continuously in the model as the climate system evolves. Prof. Thorpe pointed out that climate models include both global atmospheric and ocean models similar to those used for weather forecasting and, despite uncertainties, they successfully take account of a range of factors believed to play a role in modulating the climate system. The human input of greenhouse gases, such as CO_2 (figure 3), produces an enhanced greenhouse effect, including some positive feedbacks. These include feedbacks associated with water vapour, and reflectivity of ice and clouds. Particles in the atmosphere (aerosols), for example, from volcanic and human activities would produce cooling. Scientific evidence about aerosols has been steadily accumulating in the past 10 years and, while further research is needed, we are able to provide quantitative estimates of the cooling effect of aerosols, he said. It is necessary to incorporate the cooling effects of aerosols as well as the warming from the enhanced greenhouse effect and the associated feedbacks to account for the observed warming.

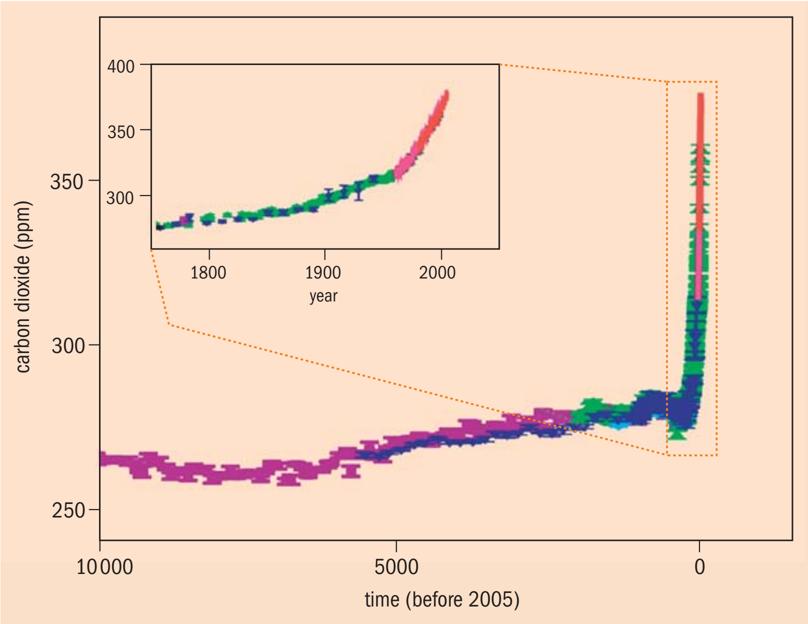

Figure 3: Changes in CO_2 concentrations over the past 10 000 years, showing a rapid rise over the past 100 years.

Prof. Thorpe also commented on the recent focus on the possible role of solar activity and cosmic rays on climate. (These high-energy particles ionize air molecules, which then act as nuclei for cloud condensation, leading to a cooling effect.) He highlighted recent studies by Mike Lockwood of the Rutherford Appleton Laboratory on the effects of solar and cosmic radiation.[7] These reveal that the solar irradiance has decreased since 1985 while the galactic cosmic-ray count has increased. Both effects should lead to cooling and therefore could not have contributed to global warming. This is influential evidence that solar effects cannot explain the warming observed in recent decades.

Comparing with observations

How are climate models evaluated? One way is to run them as "hindcasts" for periods in the recent and distant past, and compare them in detail with observations. Some features of the climate are less well simulated but others, such as the large-scale properties, are well simulated, maintained Prof. Thorpe. "There is no reason *a priori* that model uncertainties should cause systematic

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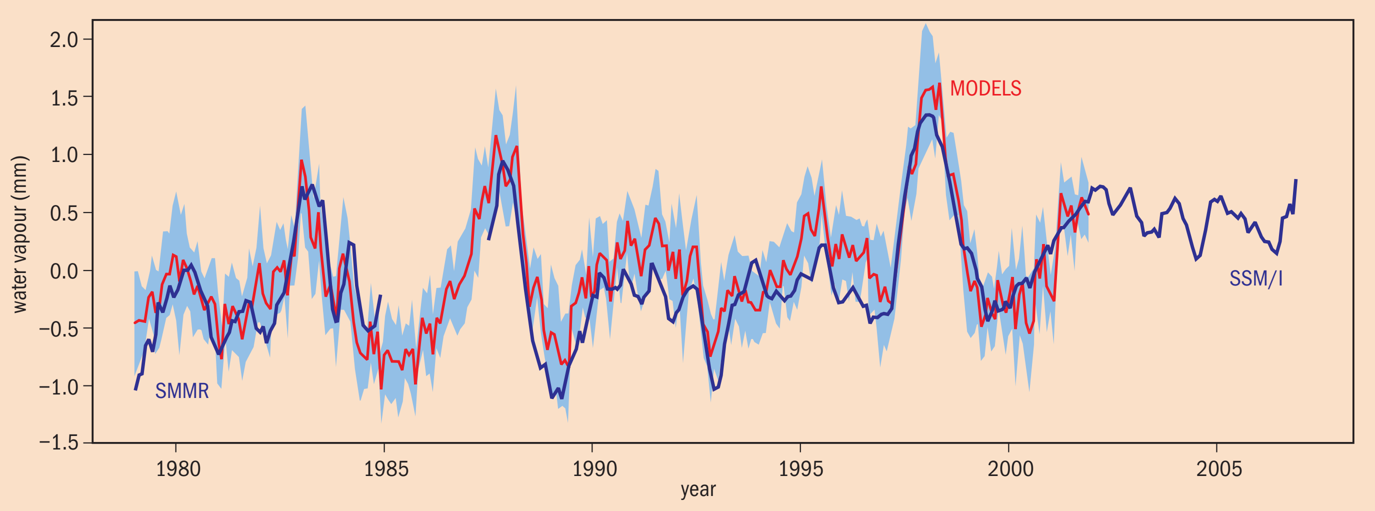


Figure 4: The comparison between model simulations (blue) of the period from 1980 compared with satellite measurements (red).

overprediction of global average warming," he said. As an example of the accuracy of the models, Prof. Thorpe gave simulations carried out on the effect of water vapour – itself a powerful greenhouse gas and the most important feedback factor.[8] Standard physics predicts that, for every degree of warming, the water-holding capacity of the atmosphere goes up by 7%, generating a positive feedback. Comparisons of computer simulations with satellite measurements from 1980 until now indicate that models are fairly accurate (figure 4). They also agree on the magnitude of the positive feedbacks from ice reflectivity. There is a large uncertainty in the cloud feedback, but all current models predict that the feedback is positive.

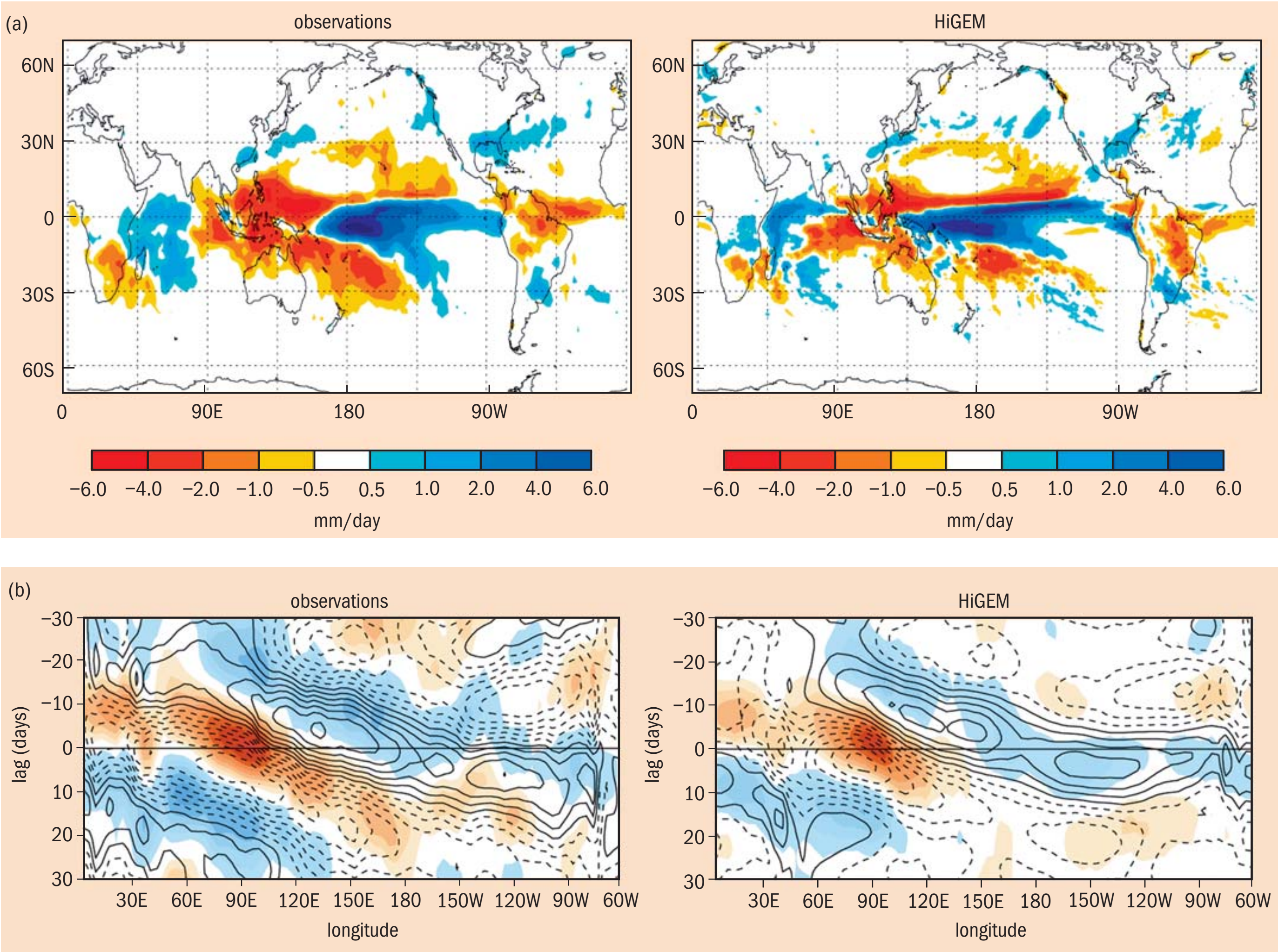
Attribution

Regional patterns of observed temperature change over the past century can be examined to allow the attribution of these changes to the various possible causes. Each factor, such as the effect of increased CO_2 concentrations, has characteristic and distinctive patterns of change. Models can also be used with or without the human input of greenhouse gases. This research has helped to pin down the causes of warming. The observed warming lies within the range bands of probability predicted by model simulations that take into account anthropogenic greenhouse gas emissions and associated feedbacks. However, if the rise in greenhouse gas concentrations from human activities is not included, the observed warming cannot be reproduced. "This is decisive evidence and forms the basis of why the IPCC produced a more definitive statement this time about attributing warming to the input of human activities," stated Prof. Thorpe.

Another approach is to compare the model projections with what has been happening in recent years. A paper published this year in the journal *Science*[9] shows that the observed temperature trends over the past 16 years lie within the bands predicted by the models. "If anything, they are at the upper end of the band, indicating that the prediction may be underestimating rather than overestimating temperature change," asserted Prof. Thorpe. Analogous simulations predicting sea-level rise show a similar pattern. These comparisons provide a convincing demonstration that models can accurately predict the evolution of global, and regional, patterns of temperature change.

Prof. Thorpe stated: "The weight of evidence collected in the IPCC report is extensive. I conclude that there is a risk of dangerous climate change resulting from the emission of greenhouse gases. However, further research is needed on basic climate processes and feedback mechanisms, particularly involving the biosphere. We need to understand the interactions between vegetation, marine life and the climate system a lot better."

More observations of trends and processes together with more computer power are needed so that new high-resolution models can be run to reduce uncertainties. Prof. Thorpe added that the NERC was playing a part in funding high-quality cutting-edge research to identify and reduce the uncertainties in our understanding of climate change. The NERC-supported HiGEM programme[10] is making detailed comparisons between state-of-the-art models and



Figures 5(a) and (b): Comparisons of the HiGEM high-resolution simulations with detailed observations of (a) rainfall anomaly during El Niño periods (blue: an increase in rainfall rate; red: a decrease) and (b) the propagation of cloud disturbance associated with the Madden–Julian oscillation over time.

detailed observations of atmospheric and ocean phenomena, including rainfall patterns (figures 5(a) and (b)). The aim is to study mechanisms of climate variability and change on timescales of days to centuries. Initial results show that the HiGEM model represents key features of the climate system, including global weather fluctuations such as El Niño, the Madden–Julian oscillation (an anomalous tropical rainfall pattern) and storms, much better than coarser-grain models. This adds important new evidence that climate models will not only reproduce global average temperature changes well but also simulate regional patterns of climate variability.

In conclusion, Prof. Thorpe noted that the vast weight of evidence in the published peer-reviewed scientific literature supports the conclusion that the observed warming over the past decades has been because of the enhanced greenhouse effect caused by the human input of gases. Also the role of aerosols, again from human activity, is to ameliorate the warming to some extent and must be taken into account. The physical principles underlying the warming are well understood and accepted by the vast majority of scientists working in the field. This is not to say that there are no uncertainties but current research is proceeding at a rapid pace to reduce them. Climate models encompass the laws of physics, and they have been, and continue to be, tested against detailed observations of the climate system. We can have confidence that the models are credible and vital to address the science of climate change.

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References

1. www.ipcc.ch.

2. IPCC 2007 Summary for policymakers *Climate Change 2007: the Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* S Solomon, D Qin, M Manning, Z Chen, M Marquis, K B Averyt, M Tignor and H L Miller (eds) Cambridge University Press, Cambridge, UK and New York, NY, US.

3. IPCC 2007 Summary for policymakers *Climate Change 2007: Mitigation of Climate Change. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, www.ipcc.ch/SPM040507.pdf.

4. M-I Lee, M J Suarez, I-S Kang, I M Held, and D Kim (submitted) A moist benchmark calculation for the atmospheric general circulation models *J. Climate*.

5. www.metoffice.gov.uk/research/hadleycentre/pubs/HCTN/HCTN_12.pdf.

6. http://hadobs.metoffice.com/hadcrut3/diagnostics/global/nh%2Bsh/annual.

7. M Lockwood and C Fröhlich (in press) Recent changes in solar outputs and the global mean surface temperature *Proc. R. Soc. A*.

8. S Bony *et al*. 2006: How well do we understand and evaluate climate change feedback processes? *J. Climate* **19** 3445–3482.

9. S Rahmstorf, A Cazenave, J A Church, J E Hansen, R F Keeling, De E Parker, R C J Somerville 2007 Recent climate observations compared to projections *Science* **316** 709.

10. www.higem.nerc.ac.uk.

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