AUSTRALIAN ACADEMY OF
TECHNOLOGICAL SCIENCES AND ENGINEERING

# CLIMATE CHANGE SCIENCE:

## An Update of Current Understanding and Uncertainties

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## Summary

The Australian Academy of Technological Sciences and Engineering (ATSE) has reviewed the findings of the 1995 Joint Academies Report[1] on 'Climate Change Science: Current Understanding and Uncertainties" in the light of developments over the past seven years including, in particular, the conclusions of the Third Assessment Report[2] of the Intergovernmental Panel on Climate Change (IPCC). The participants at an Academy workshop held in Melbourne on 4 April 2002 agreed that the prospect of human-induced climate change remains a sufficiently serious issue for Australia that the Academy should give high priority to contributing its expertise to formulation of a well-informed and balanced national response. This report[3] provides a summary of current understanding and uncertainties in the science of climate change, as elaborated at the workshop, and indicates priorities for follow-up action by the Academy.

## Introduction

In 1994, the Australian Academy of Technological Sciences and Engineering (ATSE), in association with the Australian Academy of Science (AAS) and the Academy of the Social Sciences in Australia (ASSA), carried out a study of climate change science. The study was undertaken by a team led by Professor Greg Tegart AM FTSE and including a number of Australian scientists who were lead authors of the 1995 Second Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). The Academy report[1] entitled 'Climate Change Science: Current Understanding and Uncertainties' was launched in February 1995 and distributed widely within government, industry, academia and the community. It was also distributed internationally to delegations attending the First Session of the Conference of the Parties to the Framework Convention on Climate Change, in Berlin, in April 1995.

Given the passage of seven years since the completion of the Academy study and following the completion of the IPCC's Third Assessment Report in 2001, the Academy decided to convene a one-day workshop on 4 April 2002 in Melbourne to take stock of what has changed in our understanding of climate change science since 1995. The speakers and panellists at the workshop were members of the Steering Committee and Study Team of the 1995 Study and the Australian Lead Authors for the Science (Working Group I) component of the IPCC Third Assessment Report[2]. Other participants included a number of Academy Fellows and special invitees. This report is a summary of the main outcomes from this one-day workshop.

1 Climate Change Science 1995 Current Understanding and Uncertainties. Steering Committee of the Climate Change Study. Australian Academy of Technological Sciences and Engineering, Melbourne, 100 pp.
2 IPCC, 2001. Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, 881 pp.
3 This report on the Workshop, prepared by Professor David Karoly and Professor Greg Tegart AM FTSE, was circulated to the Workshop participants (list at Appendix A) for reactions and suggested amendments, with final editing undertaken by the Workshop Co-chairmen, Mr Jerry Ellis FTSE and Dr John Zillman AO FTSE.

## IPCC Third Assessment[4]

***Observations show that the Earth's surface is warming.***

The global average surface temperature has increased over the twentieth century by 0.6±0.2°C. Air temperatures over land and sea surface temperatures have increased in both hemispheres. There has been widespread retreat of mountain glaciers, increase in global ocean heat content, and reduction in Northern Hemisphere snow cover and ice extent. Globally, the 1990s are very likely the warmest decade in the instrumental record. New analyses of data from tree rings, corals, ice cores and historical records indicate that the increase in temperature in the twentieth century is likely[5] to have been the largest of any century during the past 1,000 years, at least for the Northern Hemisphere.

***There are unexplained differences between the warming trend in surface temperature and the absence of warming in the lowest 8km of the atmosphere since 1979.***

This difference occurs mainly over tropical and sub-tropical regions. It can be partly explained by differences in spatial sampling, as well as the different responses of the two layers to factors such as atmospheric aerosols and the El Niño phenomenon. Since the 1950s, the global temperature increases in the lower atmosphere and at the surface are significant and similar.

***Atmospheric concentrations of the main anthropogenic greenhouse gases have increased substantially since 1750*** **(carbon dioxide ($CO_2$) by 31%, methane ($CH_4$) by 151%, and nitrous oxide ($N_2O$) by 17%).**

The present $CO_2$ concentration has not been exceeded during the past 420,000 years and likely not for the past 20 million years. About three-quarters of the anthropogenic emissions of $CO_2$ are due to fossil fuel burning, with the rest due mainly to land-use change, especially deforestation. The ocean and land together take up about half the anthropogenic emissions. Some greenhouse gases ($CO_2$ and $N_2O$) have long atmospheric lifetimes.

Anthropogenic aerosols are short-lived and mostly produce negative radiative forcing.

The major sources of anthropogenic aerosols are fossil fuel and biomass burning. There is much less confidence in the ability to quantify the magnitude of the direct influence of aerosols on climate and its evolution over time, than that for the anthropogenic greenhouse gases. Aerosols also have an indirect influence on climate through their effects on clouds. There is now more evidence for this indirect effect, which is negative, although very uncertain in magnitude.

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4 This section is based on the IPCC Third Assessment Report's Working Group I Summary for Policy Makers and its subsequently issued Synthesis Report.

5 Some participants at the Workshop considered that this IPCC conclusion is expressed in more confident terms than they would subscribe to - see section on 'Areas of Concern Discussed at the Workshop'.

***Overall, there have been major improvements in most processes and feedbacks included in climate models.***

Some recent models produce satisfactory simulations of current climate without the need for non-physical adjustment of heat and water fluxes at the ocean-atmosphere interface used in earlier models. There have been significant advances in the modelling of water vapour, sea ice dynamics, and ocean heat transport. There are particular uncertainties associated with the modelling of clouds and their interaction with radiation and aerosols. Several climate models reproduce the observed large-scale changes in surface temperature during the twentieth century when driven by changes in natural forcing (solar radiation and volcanic aerosols) and anthropogenic forcing (greenhouse gases and aerosols).

***Most of the observed warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations.***

Assessments based, *inter* alia, on model simulations indicate that natural forcing alone is unlikely to explain the recent observed global warming or the observed changes in vertical temperature structure of the atmosphere. All simulations with greenhouse gases and sulphate aerosols that have been used in detection studies have found that a significant anthropogenic contribution is required to account for surface and tropospheric trends over at least the last 30 years. Uncertainties in other forcings that have been included do not prevent identification of the effect of anthropogenic greenhouse gases over the last 50 years.

***Future increases in global average temperature can be expected as a consequence of continued emissions of carbon dioxide and other greenhouse gases.***

The IPCC Special Report on Emissions Scenarios (SRES)[6] produced a set of future emission scenarios based on a range of differing assumptions[7] about population, energy sources and socio-economics. Under all of these scenarios, $CO_2$ concentration grows in the atmosphere, reaching 540 to 970 ppm by 2100 (compared to a pre-industrial level of 280 ppm and a present level of 367 ppm). Taking into account the range of SRES emission scenarios and the differing results of current global climate models, global mean warming is projected to range from 1.4 to 5.8°C by the year 2100, relative to 1990. These projected warmings are higher than earlier IPCC estimates, primarily because of reductions in the assumed increase of sulphate aerosols and to some extent because of the use of a wider range of emission scenarios. Climate modelling results also indicate that the warming will be more rapid over land and in the higher latitudes. Precipitation is simulated to increase in the global average and in the mid to high latitudes, but in lower latitudes models give areas of both increase and decrease. Increases in rainfall are associated with more intense extreme rainfall events. Increases in temperature are associated with increases in the frequency of hot days, and decreases in cold extremes.

6 IPCC, 2000. Emission Scenarios. IPCC Special Report, Cambridge University Press, 599 pp.
7 Some participants at the workshop have questioned the scientific and statistical basis of the SRES emissions scenarios.

***The projected temperature increases are likely to lead to a global average rise of sea level over the period 1990 to 2100 of 30-50 cm, with a full range of uncertainty across all models and greenhouse gas scenarios of 9-88 cm.***
During the 20th century, sea level has been rising at a rate of 1 to 2 mm/year. This rate is significantly larger than over the past few thousand years. It is very likely that the twentieth century warming has contributed significantly to the observed rise, through thermal expansion of the ocean and the widespread loss of land ice. The rise in sea level will continue for hundreds of years after greenhouse gas concentrations are stabilised. Extreme high water levels will occur with increasing frequency (ie with reducing return period) as a result of sea level rise.

***Key uncertainties***
There are still many uncertainties in climate change science; major areas of uncertainty include:

- the magnitude and character of natural climate variability;
- climate forcings due to natural factors (solar and volcanic) and anthropogenic aerosols (particularly effects on clouds);
- assumptions underlying the large range of plausible future emissions of greenhouse gases and sulfate aerosols, relating to economic growth, population growth and technological progress;
- factors associated with climate model projections, in particular climate sensitivity and feedback processes, especially those involving water vapour, oceans, clouds and aerosols;
- regional projections and relating regional trends to anthropogenic climate change.

In addition to the areas of uncertainty identified by the IPCC, some participants at the Academy workshop questioned the validity of some of the scenarios of human activity, particularly those leading to the highest estimated emissions, on which scenarios had been based. It was felt that this point could not be adequately addressed by the full range of workshop participants. (See also section below on 'Validity of modelling'.)

## Areas of Concern Discussed at Workshop

Following from the summary of the IPCC Third Assessment Report by the Australian lead authors, there was a lively discussion of the key uncertainties noted above. This can be summarised as :

- ***Validity of the reconstruction of the historical record for the past 1000 years***

While there is no doubt that the extensive data from 1861 show an overall increase in the global average surface temperature - with 1998 the hottest year of the instrumental record and 2001 the second hottest year - doubt was expressed over the proxy data used to construct the historical record for the Northern Hemisphere from 1000 to 1861. The proxy data are based on tree rings, corals, ice cores and historical records which are necessarily more limited and have greater ranges of uncertainty than the instrumental data. This has ramifications for the characterisation of natural climate variability and the contribution of anthropogenic influences although it was pointed out that those using these data take the limitations of the proxy data into account.

- ***Uncertainty over the role of aerosols***

The role of aerosols is complex. Soot (carbon black ) has been found to be a more significant greenhouse component than methane, and climate forcing is being underestimated by neglecting the contribution of soot. Further, soot has a different locational effect to sulphate aerosols - which had been considered by IPCC previously. To complicate matters even further, mixed particles of soot and sulphate have been identified with absorption up to three times that of soot. There is clearly much more work to be carried out on this topic and its impact on the predicted values of temperature rise is unknown.

- ***Validity of modelling the global climate of the twenty-first century***

The wide range of emission scenarios developed as inputs to climate models leads to an extremely wide range of output parameters such as temperature rise and sea level rise. The scenario outcomes depended heavily on input data, and concern was expressed by a small number of participants that the highest figures, in particular, could unreliable. Such wide ranges of projections mean that the development of adaptation and mitigation policies needs to account for the inherent uncertainties in the science. It is clear that while climate models have improved significantly, the levels of uncertainty in the socio-economic scenarios, including the influence of presently unforeseeable technological developments are still a significant problem in projecting the future course of climate change.

- ***Continued lack of progress in estimating regional changes***

Despite the large amount of effort invested so far, considerable further progress is required before there will be confidence in detailed estimates of regional changes. From an Australian viewpoint, a better estimation would enhance the development of reliable adaptation and mitigation strategies.

## Review of the Conclusions of the 1995 Academies' Report on Climate Change Science

In the light of the findings of the IPCC Third Assessment Report, the workshop reviewed the conclusions of the 1995 Academies' Report. It was agreed that the majority of these were still valid but that a number required to be changed in the light of new findings. Specifically those[8] needing amendment - changes are in bold - were:

8 The conclusions set down in the Executive Summary on pp vii-xi of the 1995 Academies' Report were not numbered sequentially. The numbers used here align with the order of the original conclusions.

Conclusion 5 : Calculations based on global climate models **and the full range of emission scenarios considered by the IPCC** suggest that the enhanced greenhouse effect will cause a measurable and identifiable rise of **between 1.4 and 5.8°C** relative to 1990 in the average surface temperature of the earth during the next century. **Attention should be given to the economic assumptions on which the scenarios have been based.**

Conclusion 7 : **The global average surface temperature has increased over the twentieth century by about 0.6°C**.

Conclusion 8 : **The role of aerosols in the enhanced greenhouse effect is complex with both cooling and warming resulting from different types of aerosols.**

Conclusion 9 : **Oxygen and carbon isotopes measured in the atmosphere indicate that in recent decades the global biosphere has accumulated carbon, in part offsetting atmospheric increases related to carbon dioxide fertilisation but other factors could be involved. The future of the "buffering" effect is unknown as land use and climate changes proceed but the limited evidence that exists suggests that it is unlikely to continue past the middle of the twenty-first century.**

Conclusion 12 : **While** changes in climate will have significant effects on natural ecosystems, **these effects are now better understood**.

Conclusion 13 : The projected increases in temperature **for the period 1990 to 2100 indicate a sea level rise of 0.09 to 0.88 m with a likely range between 0.3 and 0.5m. Citing this middle band goes some way to recognising the uncertainty of the basis for the scenarios rather than that of the models themselves.**

## CONCLUSION

The overall conclusion of the workshop was that the prospect of human-induced climate change remains a sufficiently serious issue for Australia that the Academy should give a high priority to contributing its expertise to formulation of a well-informed and balanced national response. While it must be expected that vigorous debate will continue on the details of the science, the participants at the workshop were agreed that the Academy should now turn its attention to facilitating informed and balanced formulation of the national policy response to the greenhouse issue. This would include both Australia's role in global mitigation action and planning for adaptation to whatever future changes in climate (both natural and human-induced) can be anticipated on the basis of improved modelling capabilities resulting, inter alia, from continuing progress in climate change science.

## Appendix A

# Climate Change Science Workshop, 4 April 2002

## List of Participants

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| **Co-Chairs:** | Mr Jerry Ellis FTSE<br>Dr John Zillman AO FTSE |
| **Rapporteurs:** | Professor David Karoly (IPCC Coordinating Lead Author)<br>Professor Greg Tegart AM FTSE |
| **Attendees:** | Mr Tim Besley AC FTSE (President ATSE)<br>Dr Sue Barrell<br>Dr David Brockway FTSE<br>Mr Ian Castles AO FASSA<br>Dr John Church (IPCC Coordinating Lead Author)<br>Mr Keith Daniel FTSE<br>Dr Martin Dix (IPCC Lead Author)<br>Ms Bettye Dixon<br>Dr Paul Donaghue FTSE<br>Mrs Joy Dudine<br>Mr Quentin Farmar-Bowers<br>Dr Bob Foster<br>Ms Karen Grady<br>Dr Colin Grant<br>Mr Stuart Hamilton AO<br>Mr Alan Hayter<br>Professor Ann Henderson-Sellers FTSE<br>Dr Glen Kile<br>Mr John Laurie FTSE<br>Mr Mark Leplastrier<br>Dr Geoff Love<br>Dr Angus McEwan FAA FTSE<br>Dr Bryant McAvaney (IPCC Coordinating Lead Author)<br>Dr Ian Mair AM FTSE<br>Mr Mike Manton FTSE<br>Dr Neville Nicholls<br>Professor Henry Nix AO<br>Sir Gustav Nossal AC CBE FRS FAA FTSE<br>Mr Malcolm Palmer<br>Professor Garth Paltridge FAA<br>Sir Arvi Parbo AC FTSE<br>Dr Graeme Pearman AM FAA<br>Dr Andrew Pitman (IPCC Lead Author)<br>Professor Ian Rae FTSE<br>Mr Michael Rae<br>Dr Peter Whetton (IPCC Lead Author)<br>Dr David Wratt<br>Professor David Yencken AO<br>The Hon Sir John Young |