Australian Academy of Science
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Priorities for Australian climate change science research

Introduction

The Australian Academy of Science, in a statement on climate change on 1 July 2008 (www.science.org.au/policy/climatechange-g8+5.htm), endorsed the findings in the Fourth Assessment Report of the IPCC that 'the increases in global average temperature and sea level are unambiguous and are almost certainly primarily due to greenhouse gas emissions.'

However, the scientific knowledge underlying climate change is not complete and the Academy noted 'that there remains considerable uncertainty in the mechanisms of climate change and how it will be manifested at regional and smaller scales at which adaptation measures are required. Substantial deficiencies of understanding remain and require more research on basic greenhouse science, including the Earth's radiation balance, fluid dynamics of the atmosphere and ocean, the role and importance of the hydrological cycle in amplifying the greenhouse effect, and atmospheric carbon dioxide exchange with the biosphere and oceans.' Other areas can be added.

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There is now general acceptance of the need for adaptation and mitigation action to reduce further greenhouse gas emissions. This consensus should not cause us to lose sight of the requirement for Australian and international research efforts to better understand the contributions from different climate change processes. In particular, there are major areas of deficiency in scientific understanding of the climate system such that specific local climate change prediction remains uncertain.

Investing in climate change science

The Australian Academy of Science strongly supports the call for increased national investment in the science of climate change, with an emphasis on making systematic observations together with basic and applied research. In particular there is a need for basic research on regional forecasts, and a need to strengthen the associated observation program. The research on regional forecasts needs to include investigation of the 'skill' of forecasting, that is how well the forecasts compare with observations. Such tests can be made with 'hindcasts', for example by predicting climate development in the 20th century from an initial state at, say, 1900. More fundamentally, there is a need to examine the limits to which reliable regional forecasts are possible.

This basic research needs to be part of a collaborative national program within the international framework. This can reduce the uncertainties in our understanding of climate change processes, particularly of how global change impacts on local conditions. The program must include:

- greatly enhanced climate observing capability across the region;
- significant strengthening of Australian capabilities in theoretical analysis and modelling of the climate system;
- independent predictive climate models appropriate for Australian conditions that are accessible to and well understood by the Australian research community;
- advanced data handling with the necessary supercomputing facilities;
- training for the next generation of climate scientists; and
- effective linkages with the international programs.

Out-of-date observation systems need updating

The Australian systems for observing, monitoring and modelling climate systems, principally through the facilities of the Bureau of Meteorology (BoM) and the CSIRO, require significant upgrading and expansion. Many of the present observing systems were originally set up for different purposes. With increasing demands for improved data resolution and quality, and with new technologies becoming available, a creaking system needs major upgrades. These include improved monitoring of:

- the hydrological balance across the continent and water stored in vegetation and soils;
- changes in land use and forestry;
- spatial variation in carbon dioxide levels over the continent to identify sources and sinks;
- solar and longwave radiation fluxes;
- long-term changes in both terrestrial and marine ecosystems; and
- the dynamics of the sea ice and the continental ice of Antarctica.

The list is long but necessary if Australia is to develop an integrated response to battle the many-headed hydra of problems associated with climate, water, environment, food and agriculture, energy, biodiversity.

Understanding the Earth system requires many fields of expertise

Climate change has to be seen in an Earth-system context to include atmospheric chemistry and circulation, radiation physics, ocean chemistry and circulation, the cryosphere, the hydrologic cycle, the terrestrial land surface and the Earth below the surface, vegetation dynamics and carbon cycle including soil processes. Many feedbacks between the different components of this system occur and it is these, compounded by computational complexities, that make predictive modelling of the system so complex. Successful predictive models require a good observation-based description of what we are trying to understand – the individual components of the system and their interactions – and powerful computational capability that allows the statistical exploration of the full range of plausible scenarios.

Enhanced routine monitoring of the Earth system

The essential first requirement is an enhanced program for the routine systematic monitoring of the 'Earth system' across the Australian region to provide the observational base for climate process research. Detailed systematic observation underpins model development, but also tracks what actually happens as climate change unfolds. At present observation of the atmospheric and weather system is inadequate in Australia and may actually be declining. Monitoring of adjacent regions where much of Australia's weather and climate originates, such as the Southern Ocean and Antarctica, is less complete. These latter are of particular importance to Australia and where Australian leadership in research is needed. Continuous long-term observations of the entire climate system, with sufficient spatial and temporal detail to capture the major features of Australia's climate and its impacts on terrestrial and marine ecosystems are essential.

Regional responses to global conditions

Much of the focus on climate change is on what is happening globally. Of immediate relevance to Australia is the regional adaptation response to global conditions. The challenge for Australian climatologists is to develop more certainty about regional climate trends and predictions. Reliable rainfall predictions, in particular, are important to assist with planning for water resource management and agriculture. The consensus is that global average rainfall will increase with increasing temperatures but that regional variations may also occur. For example, there is concern that an expansion of the Hadley circulation and a poleward shift of storm tracks could lead to a drier climate for southern Australia. Despite progress (such as the inclusion of the effects of aerosols on climate) regional changes in rainfall remain much more difficult to predict than temperature because the dynamic features of climate result in an uneven spread of this increase.

The scenarios of the IPCC are not sufficiently reliable for adaptation planning in Australia. This has recently been illustrated by models (Rotstayn et al. 2007) in which rainfall simulations from a single model are shown to be very sensitive to starting conditions, due to the 'butterfly effect'. Model runs with identical atmospheric and other forcing from 1871 to 2000, and only slightly different starting conditions in 1870, gave very different patterns of regional rainfall trends for the period 1951–96. This is

not a reflection on the modelling capability but an inherent feature of the climate system where only small perturbations can result in substantially different outcomes. It emphasises the need for a more statistical approach to the interpretation of model outputs. This can only be done if models can be run many times over, hence the need for much greater computational capacity than is currently available.

The Academy notes that the rainfall projections for 2100 in the CSIRO–BoM report (2007) and subsequently used by Garnaut (2008) are not identical with the IPCC 'consensus scenario', and are somewhat drier than it. The projections of individual models have been weighted in the CSIRO–BoM report by the 'skill of the individual models at reproducing present day climate'. The notion of 'skill' in this context is somewhat subjective, and there is no agreement on what constitutes the best approach. Pitman and Perkins (2008) used different but entirely acceptable criteria for 'skill' from those of the 2007 report, and examined the resulting ensemble projections for Australia in 2050 and 2100, which are wetter. This is a reflection of the recognised uncertainty in climate modelling. Economic modelling based on one scenario that does not consider this uncertainty therefore has the risk of reaching incorrect conclusions.

Faced with these uncertainties it is essential to support basic climate science activities directed towards establishing a verifiable skill at forecasting regional climate change within Australia, and especially skill in rainfall prediction for multi-annual, decadal and longer time scales. Future developments in Australia's rainfall patterns – both in terms of observations and their analysis and modelling and its associated analyses – should be made a national research priority. A substantial strengthening of the Australian component of the Global Climate Observing System (GCOS) is absolutely essential for all aspects of managing the Australian response to climate change.

Modelling of the Earth system requires substantial super-computing capabilities

An important requirement is for very high capacity computers to provide the wherewithal for the high spatial resolution modelling needed for climate change impacts analysis relevant to local adaptive responses and, because of the inherent

chaotic nature of the solution, for running the models under different starting conditions.

While the BoM–CSIRO High Performance Computing and Communications Centre (HPCCC) and ANU National Computing Infrastructure (NCI) are endeavouring to join forces to achieve a viable capacity for state-of-the-art climate modelling, the likely available funds fall well short of what is needed to keep the Australian modelling community resourced to the standard of international collaborators, particularly if the objective is to provide both weather *and* climate predictions. The computing resources need to be of sufficient capacity to ensure that the broader climate change community can test consequences of a full range of alternative hypotheses and for the development of feedback mechanisms.

Australian contributions to international research efforts

While it is true that the IPCC requests model-run output for its assessments, and that Australia has responded (via CSIRO and the Bureau of Meteorology Research Centre), it must be understood that the IPCC is a body that issues periodic reviews and not a research coordinating body. Australian research and modelling efforts need to be directed more to the crucial international research effort coordinated by the World Climate Research Program (WCRP) and the International Geosphere Biosphere Program (IGBP). Full Australian participation in this international process requires support for independent research from all Australian scientific sectors.

Australian scientists have contributed strongly to the international research effort through the WCRP and the IGBP, as well as to bilateral and multilateral programs. But the resources to support this international involvement are now strained and thinly spread. A new Australian commitment to international climate research is needed as a matter of urgency. This will ensure:

- a seamless interface between regional and global work;
- that Australian work is competitive with, and able to take advantage of, the world's best research; and
- equitable participation in the planning and operation of global observation programs, particularly those based on satellite sensing techniques, so that they can be directed at specific Australian programs.

One example would be participation in a follow up to the current Gravity Recovery and Climate Experiment satellite mission that can monitor the hydrological balance across Australia. Another is participation in satellite altimetry missions to monitor the evolution of the Antarctic ice surface and the regional ocean surface. A further example is the use of satellite remote sensing to measure CO_2 concentrations to identify areas of CO_2 uptake and emission.

University-based research funding

To compete internationally, the research structures producing the Australian national model should include cutting edge climate science research, subject to international peer-review. The ultimate test of the research rigour, freedom and contestability will be whether it is attractive to the best climate scientists, nationally and internationally. To that end, Australia must make a commitment to bottom-up curiosity-led research on climate change, which is currently inadequately supported. There is no specific funding from the Australian Climate Change Science Programme (ACCSP) to universities at present, only to The Centre for Australian Weather and Climate Research (CAWCR). The risk is that research is directed at predetermined targets and overlooks critical new issues. A review by Solomon and Steffen (2007) of the ACCSP pointed out the importance of engaging universities in the next phase of the ACCSP, and the Academy supports that message. Further, the next generation of climate scientists needs to be trained in Australia. This will be aided enormously by funding from ACCSP and making the Australian Community Climate Earth-System Simulator (ACCESS) accessible to university researchers.

CAWCR initiative

Because of the complexities of climate modelling, our preference is for complementary and cooperative but competitive centres of expertise in climate system modelling. Since both the BoM and the CSIRO efforts risked falling below critical mass in resources and expertise, the CAWCR initiative has become the best way of keeping Australia as a viable participant in the overall international effort, with the competition and collaboration having to come from other national efforts. To simply maintain international competitiveness and independence, the scientific capacity (staffing and other resources) of CAWCR must be substantially strengthened in the near future if the Centre is to maintain critical mass and

independence from imported modules that could limit flexibility in the range of applications. Climate change modelling is one area of science where obtaining the same results as your competitor is not necessarily a good outcome if both are using the same core computer code.

Australia needs to develop separate large-scale modelling capabilities for climate and operational weather forecasting instead of attempting to do both in a single program. Limited funding may favour a single model, but runs the danger that neither aspect is done well.

Maintaining a competitive edge

In addition to providing an improved understanding of Australian climate, an important reason for maintaining a competitive edge in climate prediction is to be able to make sensible interpretations of the research produced outside the country and to be able to make critical judgements of climate change affecting Australia in the next and future IPCC reports. It will enable Australia to keep a place at the table for the next phase in global climate assessment at the kilometre scale prediction necessary for adaptation responses.

An 'Australian Climate Change Research Institute'

The priorities outlined above would be key components for an upgraded and integrated national research program into the underpinning climate change science. We have not attempted to define here what is required for a fully integrated and effective program. However it would necessarily include marine research vessels for offshore marine and Southern Ocean work, contribution to the development and use of satellite Earth-observing systems, and other terrestrial observation infrastructure. It would require investment comparable to the $3 billion a year suggested by Professor Ross Garnaut to research, develop and commercialise low emission technologies (Garnaut, 2008). Above all it would require an 'Australian Climate Change Research Institute' – with real and virtual elements – that builds on Australia's research talent. It would have its own core facility with the resources to fund collaboration between the universities, CSIRO and BoM, as well as international linkages to develop an integrated national program.

The total effort in basic climate change science required nationally and internationally is significant. In fact, it would not be unreasonable to suggest that this is one of the greatest scientific challenges faced today. It is a global problem with regional consequences and as such requires a renewed Australian effort to understand the consequences across our region. Without this effort economic modelling and adaptation and mitigation measures cannot be placed on sound footings. The costs of understanding climate change are high, but so are the costs of ignoring that there is uncertainty.

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