Australian Government

Department of Climate Change

AUSTRALIAN CLIMATE CHANGE SCIENCE

A NATIONAL FRAMEWORK

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Climate change is the overarching issue this generation and those to follow must address and it will shape the context influencing much done by individuals, government and private organisations

The Hon Kevin Rudd, Prime Minister of Australia, 2008

Executive summary

Climate change science has been and will continue to be essential in supporting the three pillars of the Australian Government's climate change policy: action to reduce greenhouse gas emissions, action to adapt to climate change that we cannot avoid, and action to help shape a global solution.

Australian science has provided a foundation for climate change policy development to date, and international leadership in several areas of climate change science, particularly in the southern hemisphere. An Australian capability is important because science generated in the northern hemisphere, where most research is done, will not provide all the information needed for Australian decision making. Climate change science is entering a new phase of complexity as decision makers and the public demand greater insight into likely impacts and the effort required for mitigation and adaptation.

The National Framework for Climate Change Science (the Framework) identifies national climate change science priorities for the coming decade and sets out ways to harness our full science capacity to address them.

The focus of the Framework is fundamental climate system science, which provides essential system knowledge to understand climate change impacts, develop adaptation strategies, and manage carbon emissions. The scientific research proposed under the auspices of the Framework is designed to interact closely with the adaptation response agenda, with mitigation science and technology, and with efforts to develop more effective policy to deal with the climate change challenge.

The Framework comprises four main elements: challenges, capabilities, people and infrastructure, and implementation.

The *challenges* are key areas where climate change science must deliver information to inform important decisions over the next decade. They are: understanding and predicting future changes in greenhouse gases; better projections of future rainfall, evaporation and other climate features that affect our water resources; climate change influences on coasts and oceans, such as sea level rise and acidification; future extreme events including cyclones, flooding rain and storm surge; and processes in the atmosphere such as cloud physics that limit our ability to predict future climate.

The *capabilities* that Australia must maintain or develop to meet these challenges are: improved climate observations; better understanding of key climate processes such as El Nino that affect Australia; integration of climate observations and climate change modelling; predicting future climate, especially over the 10-20 year 'window' where current methods require substantial development; and integrated assessment models that link climate to social and economic systems.

Australia must address significant constraints in *people and infrastructure* in order to support these capabilities and meet the challenges. Key areas where more skilled

workers or improved infrastructure are required include earth system modelling, supercomputing and ocean observations.

Implementation of the Framework will require national coordination, and coordinated adequate investment. A National Climate Change Science strategy with the following features would be best placed to provide necessary national direction and coordination of climate change research efforts.

1. A high level coordination group comprising major funding bodies, key research organisations and senior scientists and chaired by the Chief Scientist. The coordination group will develop and oversee execution of an implementation plan for this Framework.
2. The implementation plan will draw on the resources of all relevant organisations. Where necessary, the high level coordination group will facilitate formation of cross-institutional teams to advance key elements of climate change science.
3. The Chief Scientist will report annually to the Minister for Climate Change and Water and the Minister for Innovation Industry Science and Research on progress in implementing this Framework.
4. The Department of Climate Change will establish a mechanism to liaise with States and Territories and other stakeholders on climate change science, with a particular emphasis on ensuring the national program delivers useful information about likely future climate change.

1. Introduction

Australia faces serious risks from human-induced climate change. We are exposed to heat, drought and tropical storms, we are home to many globally important and vulnerable ecological systems, and Australians are overwhelmingly coastal dwellers. Our primary and secondary industries and our urban centres face ongoing water limitations. Large-scale climate change impacts are foreseeable across these areas, and many more.

Success in minimising the potential economic, environmental and social dislocation caused by climate change – and in capturing new opportunities for productivity growth inherent in emissions reduction and adaptation– will require expanded scientific understanding. We must know how and why our climate has been changing, and how and why it will change into the future.

The Review of National Innovation report Venturous Australia identified climate change adaptation and mitigation research as one of its top five innovation priorities. The Garnaut review found that: *"Addressing the uncertainty and gaps in knowledge at the most fundamental levels of climate science and at the intermediate stages of analysis of climate impacts has large public good dimensions. There is strong justification for Australian governments expanding funding to these research areas on a long-term basis".*

In short, quality science is essential to support the Australian Government's three-pillar climate change policy response.

2. An Australian perspective

Climate change science is a global endeavour - the climate system can only be understood if it is analysed on a global scale. At the same time, Australia's climate has some unique characteristics influenced by a distinct set of climate drivers.

While Australia must be part of the global climate change science effort, we cannot rely on others to produce all the science Australia needs to understand the aspects of climate change relevant to us and to inform effective policy responses appropriate to our national circumstances.

Australia has developed world-class climate change science capabilities and made important contributions to global understanding. For example, Australian scientists furthered global understanding of the physics and chemistry of the Southern Ocean, and how it affects the climate in our region and globally. They have led pioneering studies on what drives sea level rise, how it might vary across regions, and projected changes to extremes of sea levels. They are exploring the possible link between the surface cooling caused by air pollution in Asia and increases in monsoonal rainfall in tropical north-west Australia. Australian scientists have studied historical changes in our rainfall patterns through tree rings, speleotherms (mineral deposits formed in caves) and coral reefs to put current day drying trends in a proper historical context.

Australia's international standing is reflected in our involvement in major international scientific programs, including the World Climate Research Programme, Global Atmosphere Watch, the International Geosphere-Biosphere Programme, and the Global Climate Observing System. Our direct contributions to the scientific assessments of the Intergovernmental Panel on Climate Change have been substantial. Six Australian scientists, were lead authors for the 2007 Fourth Assessment Report's Working Group 1 (The Physical Science Basis), with a further 22 Australian scientists being contributing authors– a large contribution relative to our population.[1]

The quality of Australia's science contribution is also demonstrated through a wide range of peer-reviewed papers in international science journals, including *Nature* and *Science,* and nationally through high-level scientific assessments provided to the Australian Government through the Australian Academy of Sciences and the Australian Climate Change Science Program.

Australia's participation in international climate change science has provided benefits that greatly exceed the dollar costs. One example is the global network of Argo floats that provides Australian scientists with information about the oceans that is beyond the means of any one nation to finance.

The Australian Community Climate and Earth System Simulator (ACCESS) is another example (see Box 1).

Australia's strong contribution to the global scientific effort, and history of international collaboration, is now at significant risk.

A major climate change science skills shortage in our science agencies is developing and better career paths are required to address this. Our physical infrastructure is in urgent need of renewal. We are facing increasing demands from decision makers for more detailed and specific information, and increasing quantities of data require more sophisticated analyses as our understanding of the climate system deepens.

Part of the solution must be to improve cooperation between Australia's research institutions. The 2008 Cutler review of the National Innovation System and the Strategic Roadmap for Australian Research Infrastructure have both made this point, as for example in the statement: "*Many issues, for example climate change . . . . cannot be addressed effectively in a piecemeal or segregated way and demand engagement and cooperation between researchers*"[2].

> **Box 1 - Australian Community Climate and Earth System Simulator - ACCESS**
>
> Australia's global contribution to climate change science has returned significant benefits through access to international knowledge. For example, our investment facilitated international collaboration on the development of ACCESS, enabling Australian scientists to focus our efforts where we have specific national interests and a comparative advantage.
>
> ACCESS comprises a suite of coupled climate system modules which simulate parts of the global climate system, such as the atmosphere, oceans, sea ice and land surface. It will deliver a new generation of numerical models to improve our predictive ability across the full gamut of time scales from weekly weather forecasting to seasonal prediction to climate prediction at the decadal to century scale.
>
> International collaboration has resulted in the UK Met Office providing the atmospheric model, and the US National Oceanic and Atmospheric Administration Geophysical Fluid Dynamics Laboratory the original ocean model. The sea ice model was originally developed by the Los Alamos National Laboratory. These models have been heavily improved for conditions by Australian scientists and have been coupled to an Australian land surface model developed by CSIRO, UNSW and ANU to yield the comprehensive Australian earth system simulation capability known as ACCESS.

The signs are promising. For example, the CSIRO and Bureau of Meteorology – Australia's most significant individual climate research organisations – have joined forces to create the Centre for Australian Weather and Climate Research (CAWCR). Australian universities are also increasing

[1] However as pressure on resources devoted to climate science has increased, it has been difficult to maintain our historical contributions to WG1 authorship, for which in 1995 Australia contributed a very influential 9% of authors.
[2] See: http://www.innovation.gov.au/ScienceAndResearch/Documents/Strategic%20Roadmap%20Aug%202008.pdf

their climate change science capacity, with groups such as the Universities Climate Consortium, the Australian Antarctic Division and the Antarctic Climate and Ecosystems CRC contributing significantly to advancing science in areas as diverse as sea ice and ocean circulation responses to changed weather patterns, sea level rise, bushfires and climate change, and plant responses to increasing carbon dioxide levels.

Increasing this level of collaboration is one important goal of this National Framework for Climate Change Science. Others, as outlined below, include the need for targeted investment to provide the necessary capability in infrastructure, people and climate observing capacity.

3. A National Framework for Climate Change Science

The National Framework for Climate Change Science provides an approach to bring together Australia's climate science expertise to deliver the essential climate science needed for an effective national response to climate change. It links this expertise with social and economic analysis.

The Framework will capitalise on Australia's past investment and achievements, focusing on areas of national priority – the 'challenges' – and expanding our effort in crucial areas where our current capability is either missing or inadequate. It will help ensure that Australia has the critical climate change researchers, skills and infrastructure to support government policy and actions on climate change now and in the future (Figure 1).

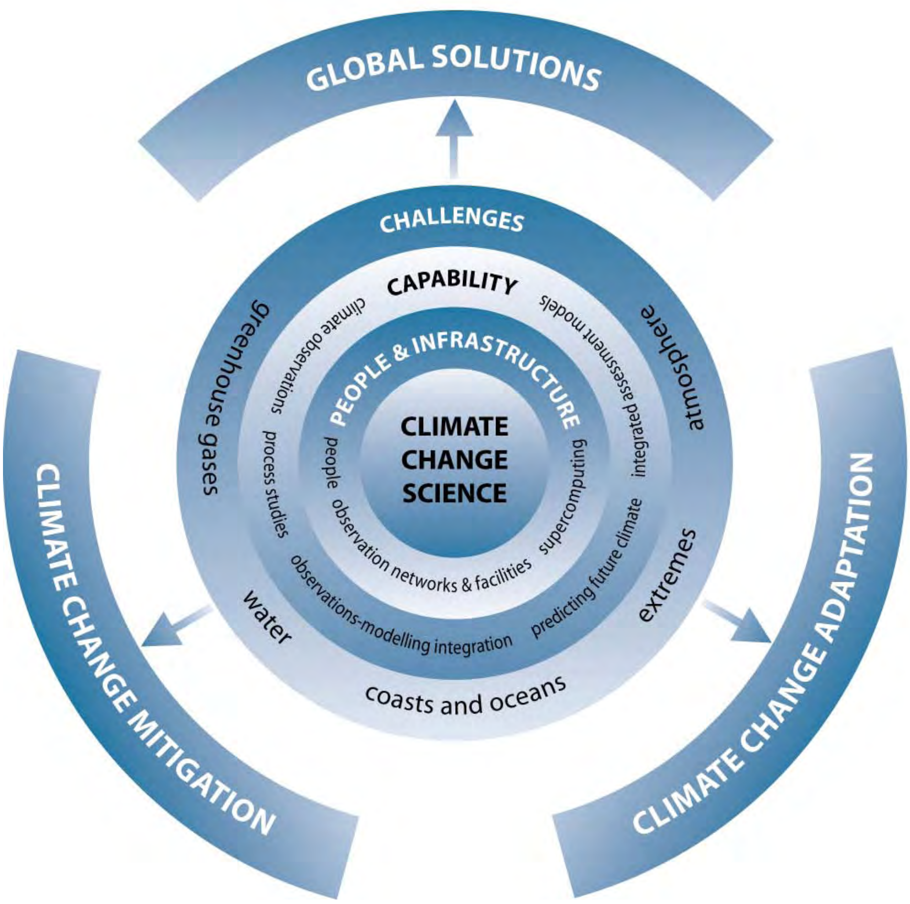

Figure 1. Schematic representation of the Framework

This National Framework covers ‘fundamental climate system science’ - the scientific observations, process studies and modelling studies that help us understand the systems, mechanisms and feedbacks that determine changes through time of the Earth’s climate including changes forced as a consequence of human activities.

This is the *essential* system knowledge without which adaptation strategies and mitigation strategies cannot readily be built - we need to know to what climate future we are adapting, and how this will be influenced by international efforts to reduce levels of greenhouse gases.

This National Framework does *not* include the science of adaptation (how human activities or management of natural ecosystems may need to change in response to the impacts of climate change). However, the fundamental science described here will provide essential information about likely future climate to support adaptation science, and close links will therefore need to be established with the adaptation research community, and in particular with the National Climate Change Adaptation Research Facility (NCCARF) and the CSIRO Adaptation Flagship. Nor does this Framework include the development of technology that reduces greenhouse gas emissions, although close interaction will be required with the mitigation science and technology research communities, and with the policy research communities that are involved with efforts to develop more effective societal responses to the climate change challenge.

Some areas of science sit at the boundary between what is defined here as ‘fundamental climate system science’ and adaptation science. These areas could, with justification, be either included in or excluded from this framework. For the sake of clarity, the following areas are within the scope of this framework:

- Linking climate with social and economic systems (see section 3.2) – included because social and economic factors are able to be incorporated in the ‘earth systems modelling’ framework.
- Climate projections science, which uses a range of techniques to deliver climate projections at the spatial and temporal scales required by decision-makers – included because of its link with climate modelling and observations.

3.1 The challenges

Australia’s climate and weather influences our way our life, economic activities, and the natural environment.

This Framework identifies areas where climate change science will need to deliver information that will inform important decisions over the next decade.

Greenhouse gases

Climate change is largely driven by increasing levels of atmospheric greenhouse gases. Uncertainty about the future capacity of forests, soils and oceans to store carbon threatens to undermine the effectiveness of strategies to reduce greenhouse gas emissions. How climate changes might impact on future methane and nitrous oxide emissions from agricultural activities is also uncertain.

The challenge is to track, understand and predict future changes in greenhouse gas levels, and in the natural stocks and flows of carbon, so that global targets to reduce emissions achieve what they are designed to do. Ocean and terrestrial carbon cycle research is critical to inform discussions and negotiations on national and global emission reduction targets.

Recent observations suggesting a weakening in the Southern Ocean's capacity to store carbon demands an intensified scientific effort to determine the physical and biological processes that control the uptake and release of carbon from the oceans. Similarly we need a greater focus on how rising temperatures, changing moisture availability, and altered fire regimes, for example, will affect the ability of vegetation and the land surface to take carbon out of the atmosphere and store it.

Broad-ranging research on the carbon cycle is needed, for example observational research carried out at Cape Grim in Tasmania and in Antarctic ice cores.

Water

Dramatic reductions in rainfall, coupled with increased temperatures, have led to even more dramatic reductions in run-off over southern Australia. This has had serious impacts on the southwest of Western Australia, northern and eastern Tasmania, the southeast and eastern continental seaboard, and most notably the Murray-Darling Basin. There is a great risk that long periods of diminished rainfall and increased evaporation will become more frequent as a result of climate change, reducing the amount and reliability of water supply to agriculture, communities and ecosystems, and making water resource management increasingly difficult.

The challenge is to provide better information about likely future climate to help manage Australia's increasing demand for urban water, and water for agricultural use, environmental flows and hydroelectric energy production, in the face of significantly diminishing supply due to a changing climate.

Specifically targeted research is needed to establish the role of climate change in southern and eastern Australia's observed drying trend and the associated changes in hydrology, evaporation and run-off. In particular research work to focus on the drivers of interannual and decadal variability in the hydrological cycle – the El Niño-Southern Oscillation (ENSO), the Indian Ocean Dipole, and the Southern Annular Mode – and the interaction of anthropogenic climate change with the processes controlling these modes of variability, including manifestations such as trends in the position and strength of the Sub-Tropical Ridge.

The influence of land cover change on local and regional patterns of rainfall and evaporation also needs to be further explored and assessed. An enhanced effort in paleo-hydrological research would help clarify the long-term patterns of natural variability of the hydrological cycle, leading to a more reliable assessment of the role of anthropogenic climate change in the observed rainfall and water availability trends in Australia over the past century and into the future. This work would provide the essential information on rainfall levels expected under climate change that are required by water managers for future planning.

Coasts and oceans

Many of Australia's coastal communities are vulnerable to coastal inundation, erosion and infrastructure damage from sea-level rise and extreme weather events associated with climate change. These potential impacts also undermine current planning guidelines.

Ocean warming, changing ocean currents and ocean acidification are also increasing the stresses on marine species, changing their distribution and putting many marine ecosystems at risk. This has potentially severe consequences for marine resources and the communities that depend on them. The corals of the Great Barrier Reef and the kelp forests off northeast Tasmania are examples of iconic ecosystems under stress from climate change.

The challenge is to provide quality information about likely changes in sea level, storm surge and extreme events that will enable Australians to manage the multiple uses of coastal and marine environments in a manner that acknowledges the risks and minimises the consequences of climate change.

An expanded program of climate science can provide important information on the factors that influence the magnitude and rate of sea level rise, including the dynamics of the large polar ice sheets under prolonged warming. Australian science has a critical role to play in the study of the Antarctic ice sheets, given our location and the diminishing investment by northern hemisphere countries that are increasingly focused on the future of Arctic ice cover and the Greenland ice sheet.

Research into sea surface temperature changes and the circulation of the Southern, Indian and Pacific oceans is crucial on a number of fronts – from understanding their influence on rainfall patterns across southern Australia to identifying the implications for the productivity of ocean ecosystems as our coastal boundary currents change.
The recent expansion of Australia's ocean territory means that Australia has the most land mass and ocean territory at high latitudes, and we are now the only country with a major field research program on Antarctic sea-ice characteristics and processes and their potential response to climate change.

Australian research will need to play a leading role in the global effort to determine the consequences of ocean acidification for the marine biosphere, especially for coral reefs in our tropics and primary producers in the high latitudes of the Southern Ocean. Others will not respond to these scientific challenges on our behalf.

We must also boost our research effort in the tropics, to quantify the effects of climate change on the intensity of tropical cyclones and how they will track along our coasts. Without this investment, our risk assessments will remain constrained by uncertainty.

Extreme Events

Australian society and our supporting ecosystems face a highly variable climate in which extremes of weather and climate pose an ongoing challenge. Risk assessments show that our natural and managed systems are highly vulnerable to increases in the frequency and scale of climate-driven extreme events such as drought, heat waves, bushfires, floods, storms and coastal inundation. Moreover, changes in the frequency of occurrence of extreme events can be much larger than changes in the average climate.

The challenge is to provide the information and knowledge needed for national adaptation initiatives to minimise societal disruption and costs associated with changes in extremes.

Extreme events drive extreme impacts. To counter the risks in this area, a much stronger research effort is needed to scale the information from global climate models to the regional and local levels, at which most extreme events occur.

Research outputs need to be well structured to support adaptation research, by working closely with the adaptation research community. The credibility and reliability of the fine-scale projections should be evaluated using thorough verification tests against observations and, where available, against paleo-climate data describing past climatic extremes.

Atmosphere

The atmosphere is where we live – it is what we breathe. Changed climate is experienced in changed patterns of daily weather, through changes to daily averages, trends, variability and extremes that impact on all aspects of daily life.

The challenge is to improve our ability to predict atmospheric behaviour across short, medium and long timescales. To do this we need to address major gaps that remain in our understanding of how the atmospheric component of the climate system behaves. This component delivers our daily weather, the quality of the air we breathe, the seasonal climate and rainfall outcomes, and averages up across the long-term to define our climate.

The IPCC has identified the critical scientific issues that need attention to improve our understanding and predictive ability of atmospheric behaviour under climate change. The World Climate Research Programme (WCRP), Global Climate Observing System (GCOS) and International Geosphere-Biosphere Programme (IGBP) built on the IPCC's work and further described these knowledge gaps in an international joint meeting hosted by Australia in Sydney in October 2007[3].

These core scientific needs include better understanding and better representation in models of processes such as cloud dynamics and convection, radiative transfer, cloud physics, aerosol-cloud interaction, atmospheric chemistry and the changing teleconnections between phenomena that influence Australian climate, such as ENSO, the Sub-Tropical Ridge, the Southern Annular mode, and stratospheric ozone depletion.

3.2 Capability

An effective national science effort, which delivers on these challenges, must be based on a scientific capability encompassing observations, process studies and model development, leading to quantitative prediction.

Climate observations

Long-term, consistent records of the behaviour of the climate system (atmosphere, land surface, ocean, the marine and terrestrial biospheres, and the cryosphere) underpin climate change detection and attribution, provide vital information with which to test models, and support the development of adaptation and mitigation responses.

Priority data streams include:

- annual assessments of temperature and precipitation change;
- records of CO_2, other greenhouse gas and aerosols from the Cape Grim base-line station;
- ice core records;
- changes in ocean salinity and temperature, and in sea ice extent and thickness, in the Southern Ocean;
- measurement of the fluxes of carbon, water and energy between the Earth's surface and the atmosphere;
- changes in sea level

[3] See: http://wcrp.wmo.int/documents/SydneyWorkshopRep_FINAL.pdf

- changes in ocean acidity; and
- observed changes in extreme weather events, such as the frequency and intensity of tropical cyclones, heat waves, thunderstorms, heavy rain and hail.

Managing and sharing data and climate information is a major challenge. An increasing number of remote sensing platforms, and a range of fixed observation networks, are delivering rapidly increasing volumes of climate data. Climate scientists are reaping great benefits from the ICT revolution as rapid developments in sensors and sensor networks will provide a quantum change in our ability to observe and understand the climate system. Systematic coordination of these activities, including linkage to international space-based observing programs, could provide access to considerable data with significant returns for the climate community. User communities are seeking efficient and effective mechanisms for access to climate change information, especially to underpin their policy and decision making.

Climate process studies

Process studies lead directly to improvements in climate system information. Improved characterisation of many atmospheric, oceanic, terrestrial, cryospheric and hydrological processes will support the coupled model components needed for an Australian climate (Earth) system modelling and prediction capability.

Elements of the climate system affecting Australia that require focussed attention via process studies include cloud dynamics and feedbacks, aerosol (air pollution, dust, and smoke) effects, tropical convection, high-latitude sea-ice and ocean interaction, the dynamics of Antarctic ice sheets, deep ocean overturning and ocean carbon uptake, land surface-atmosphere exchange and the dynamic role of vegetation interacting with changing climate.

Observations-modelling integration

Observations, models, and information from process studies can now be brought together in a new type of scientific analysis, leading to better understanding of climate processes and their interactions that produce system-level behaviour. This integration (sometimes called *model-data fusion*), leads to better identification of key climate processes and feedbacks. It enables improved parameterisations of climate processes in models, and improved evaluation of models against the historical climate record prior to their use for climate projections.

This area of research is a major focus within the global scientific community.

Predicting future climate

Australia needs information about climate change at all time scales (days, months, years, decades and centuries) and across the range of spatial scales (global, regional and local). We currently have capacity to provide limited information about climate over a 30-100 year period, seasonal (3-9 month) forecasts have moderate accuracy and daily forecasts are highly developed. Our capacity to provide information on the 10-30 year time scale of interest to many decision-makers is almost zero.

The Framework will build a new capability to predict the behaviour of the climate system over this intermediate, decadal timescale and improve the quality of projections for longer periods (30 years or more). This will require research dealing with carbon cycle dynamics, aerosol and cloud dynamics, vegetation dynamics and changes in frequency of extreme events.

Achieving reliable, decadal-scale predictions, at spatial scales from global to local, would have enormously practical social, economic and environmental benefits. The challenge is to determine whether this is scientifically possible, noting one specific advantage in working on the immediate decade or two being that atmospheric greenhouse gas levels and thus climate predictions are less sensitive to the details of greenhouse gas emission trajectories than at the century timescale.

Developing and testing such a prediction capability will be supported by a rapidly increasing ability to assimilate climate observations into modelling frameworks in real time. As noted earlier, targeted process studies will improve the characterisation of fundamental features of the climate system that are especially relevant to variability associated with climate cycles such as ENSO.

The Framework recognises that a move to what has been called a 'seamless prediction' climate modelling capability, covering all timescales from weather forecasting to seasonal prediction to decadal and century-scale climate projection, will provide essential support to Australian policy and decision-making analyses aimed at:

(1) global solutions in the context of IPCC Working Group 1 deliberations;
(2) detection, attribution, and impacts analysis for adaptation, in the context of IPCC Working Group 2 deliberations; and
(3) setting and tracking greenhouse gas mitigation targets to avoid dangerous climate change, in the context of IPCC Working Group 3 deliberations.

This capability must be comprehensive, and built on the highest quality data, information and modelling. It must encompass modelling the climate at global, regional and local scales, to support effective policy making.

Linking climate with social and economic systems

Providing a national, integrated analysis of the influence of climate change across the human systems (economic and social), not just the natural biophysical systems, is a new national challenge. There is an emerging need for a new predictive capability in Integrated Assessment Models (IAMs) (see Box 2) to be developed in parallel, but tightly linked to the full-blown biophysical climate models. IAMs trade off complexity in the physical climate modules to enable incorporation and coupling with economic and social models. This developing field of global integrated assessment modelling is being taken up quickly in, for example, the IPCC deliberations around scenario setting that cut across Working Groups 1-3.

Recently Australia has begun intellectual development in this area. It will provide an exciting platform to enable innovative new advances by the policy- and decision-making communities as they pose new questions about Australia's best options for the future. Only IAMs will be capable of answering these new, cross-sectoral, integrative policy questions.

This new IAM initiative will build on the very early and tentative work that yielded an embryonic integrated modelling view of the effects of climate change on the Australian economy, provided as input to the Garnaut review by ABARE and CSIRO. Its initial objective would be to extend this approach, based on coupling for Australia of existing climate, economic and social system models to develop a more robust coupled modelling tool. The scientific objectives at the outset will be to identify what key additional feedbacks arise in the coupled system when economic and social responses are able to vary dynamically in the model and in turn influence the pace of change as the climate responds to greenhouse and other human-mediated forcings.

Box 2 - Integrated Assessment Models

Climate scientists worldwide are pursuing more knowledge about the dynamics of the climate system under anthropogenic forcing. Policy makers also have sought to respond, but in the main are restricted to standard economic models and highly simplified climate models to plan adaptation response and mitigation strategies. The urgent demand for better tools is evident in the alacrity with which the ABARE-CSIRO Integrated assessment model, GIAM was used in the Garnaut Review. Despite the fact that it is at a very early stage of development, it has provided analytical detail unavailable from any other Australian or overseas modelling platform. Some of this detail, such as projected changes to Australia's terms of trade under climate change, has made an important contribution to the Garnaut Review.

The setting of a national emissions target and Australia's negotiating position in the development of a post-Kyoto treaty requires the development of Integrated Assessment Models (IAMs) that model climate but are also dynamically coupled to economic and social models that resolve Australia independently within the global system. Just as in the case of our biophysical earth system modelling, such Australian-centric integrated modelling tools will have to be developed largely by Australians, in Australia.

Most integrated assessment models in current use employ poorly resolved (or unresolved) climate models. Experience with GIAM suggests that strong coupling between the climate and the economy and other aspects of social dynamics occurs at the regional scale. Using globally averaged climate and economic models can severely underestimate the strength of the feedbacks. Furthermore, few IAMs at the moment attempt to deal with social dynamics other than in rudimentary and prescriptive ways, but the response of societies to climate change and to mitigation measures we might deploy will be critical in determining the course of future greenhouse gas emissions, and thus future climate.

Integrated assessment modelling is expected to play a much greater part in the future of climate science than hitherto. For very good reasons we are committed to developing ACCESS as a complex, high resolution, fully coupled Australian biophysical earth system model for IPCC's next assessment (AR5). But we must also look more broadly, beyond AR5, to related modelling tools in the form of Integrated Assessment Models that not only resolve climate but are coupled dynamically to economic and social systems. The path we take to arrive at this point needs careful thought and planning. This has commenced in the Australian science community. The imperative for immediate action is that unless we start now, we will struggle to play a significant role in the Integrated Assessment community through the next decade, an outcome that would limit the ability of Australian policy- and decision-makers to manage Australia's national response to climate change.

3.3 People and infrastructure

Appropriate skills, infrastructure and communication mechanisms are fundamental to an effective national climate change science effort.

Adequate investment in skills (education, training and targeted recruitment), infrastructure (major equipment and facilities) and communication (exchange of knowledge, engagement of other researchers, and informing policy development) is an essential element of the national Framework. The Framework identifies key areas for sustained support and development to ensure Australia has the underlying capability and capacity needed for an innovative and effective national climate change science effort and to deliver the information needed by the adaptation and mitigation research communities and those communities engaged in climate science priority setting and research.

People

'*Human capital is central to innovation*'[4]. However it is evident that the current level of effort devoted to climate change science in Australia is significantly below what is required to address the nation's priority climate science needs.

The ACCESS initiative is one example of a significant shortfall in Australia's research capacity. The Australian team is developing this complex product with only 50-60% of the staff available to groups building equivalent models in other countries. There is serious doubt about whether this level of resources will allow development in Australia to keep pace with world's best practice. This shortfall is brought into sharper focus when considering that Australia is potentially more exposed to the impacts of climate change than other developed nations.

The historically strong performance of Australian climate science in government agencies is heavily based on individuals nearing the end of their careers, with too few prospects for succession in place. There is a pressing need for more early and mid-career researchers in all of the major climate research organisations in Australia. The lack of long-term positions for young researchers in the various institutions and a lack of creative and stable career pathways for young researchers in science itself are critical issues.

To attract and keep the best and brightest of the next generation of scientists, Australian research agencies need to be far more competitive globally in terms of salaries and supporting infrastructure. The numbers of trained support staff (e.g. personnel trained in data management and interpretation, and software engineers) are also falling. While scientists currently take on some of these roles, this is a highly inefficient solution that represents a growing cost to program quality, competitiveness and effectiveness. Longer term, secure investment in people at this level of the research enterprise must also occur to maintain a robust national science effort.

Observational systems, networks and facilities

A national observational capability of oceans, atmosphere, cryosphere and terrestrial systems affecting or affected by climate change is essential to inform the research program. Australia is responsible for the third largest ocean territory in the world, is particularly climate sensitive and our climate is heavily ocean influenced. Australia currently has a reasonably well developed ocean climate observing capability in the Integrated Marine Observing System /Argo networks established under the National Collaborative Research Infrastructure Strategy (NCRIS), however achieving long-term support to maintain and expand our observational systems remains a challenge.

Seventy-seven percent of Australia's ocean territory is blue water in the Southern, Indian and Pacific oceans. These three oceans influence the behaviour of Australia's unique boundary current systems including the economically important East Australian Current and the Leeuwin Current. The Antarctic Circumpolar Current flows from west to east around Antarctica, mixing the waters from the Pacific, Indian and Atlantic Oceans. Sea ice conditions and ice shelves on the Antarctic coast are profoundly influenced by Southern Ocean processes and, in turn, provide feedbacks that influence ocean circulation.

Despite the scale of these oceanic influences, Australia has only one 37-year old blue water research vessel which operates half-time and is due for decommissioning in 2011, and one icebreaking research vessel that is nearly 20 years old. This vessel is

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[4] See NIS Review report, *venturous australia*, Chapter 5, Cutler & Co P/L, 2008.

only available for up to 60 days per year, and only if the very significant operating costs inherent in a 95m vessel can be sourced. The Australian Government is considering strategies for replacing the Marine National Facility.

The recent NCRIS Terrestrial Ecosystem Research Network (TERN) initiative has developed a conceptually sound science case for a terrestrial ecosystems observation network and data management/synthesis platform. The initial funding, however, is inadequate to deliver all components of the system at a resolution suitable to monitor ecosystem contributions and responses to climate at a continental scale.

In this context it is essential that the atmospheric and terrestrial climate record over Australia be at least maintained, and preferably that the weather and climate observational system be enhanced in a way that supports better observation of extremes of weather. High quality, comprehensive observations of weather extremes and trends over time are essential for detecting and attributing causes of climate change, as well as informing adaptation responses. An enhanced network is also the platform from which to support the development of a TERN that extends the observations to direct measurement of terrestrial carbon exchange, and will enable the roles of associated nitrogen and water exchange in regulating biological carbon exchange to be determined.

Supercomputing

Australia's current supercomputing capacity is inadequate to support the move towards Earth system simulation. Figure 3 depicts the increasing complexity with time as climate system models have evolved.

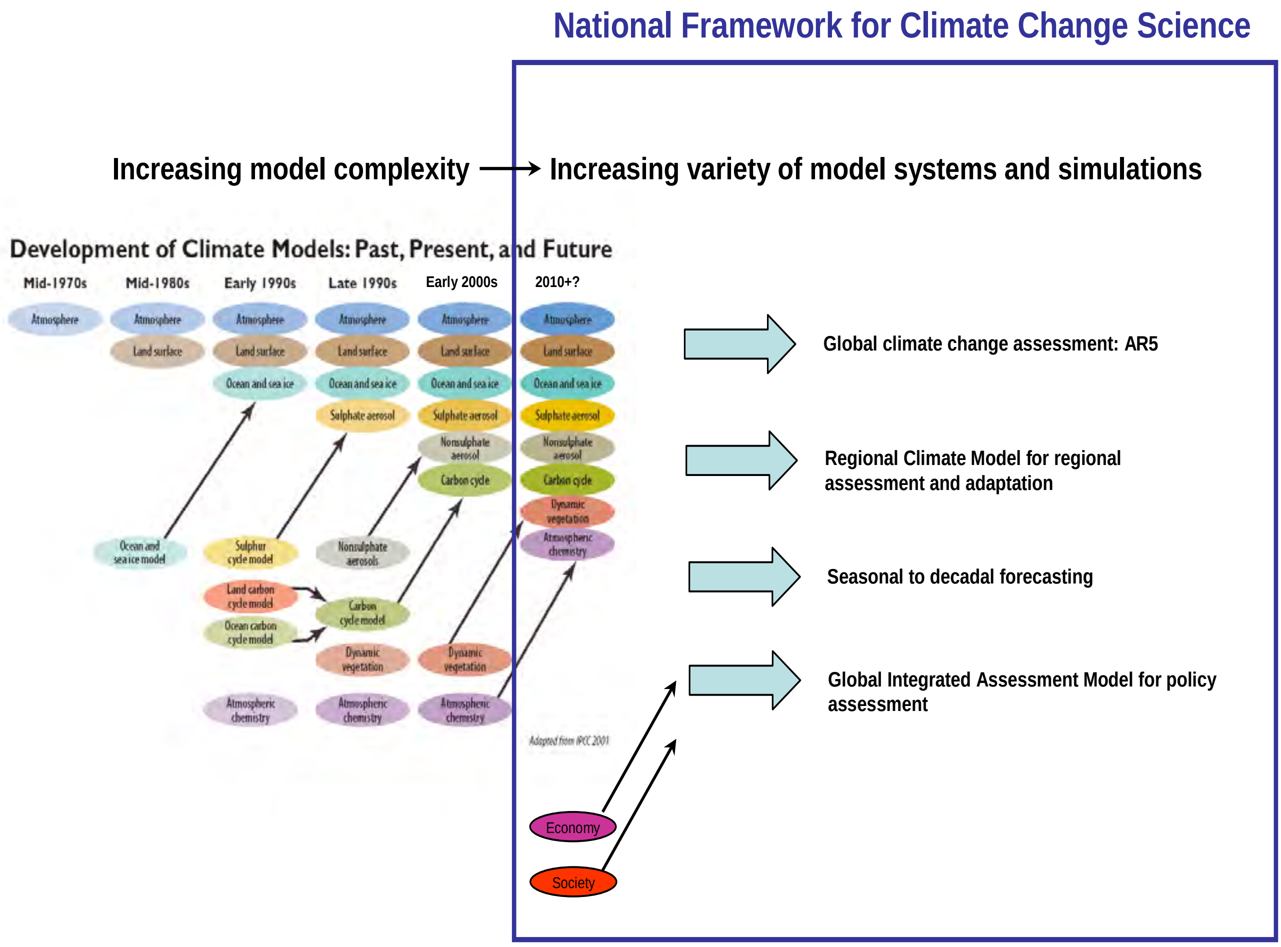

Figure 3. Historical evolution and complexity of climate system modelling.

The growing needs for regional downscaling to address localised policy issues and integrated assessment modelling mean that regional climate models and integrated assessment models need to be supported in addition to the global climate system model. Without additional capacity it will be impossible to meet the challenges set out above.

This is a threshold issue (see Box 3), which has been recognised in the Final Report of the Garnaut report issued in September 2008 [see Ch 15]: *"This suggests that greater effort and funding be allocated as part of the renewal of the Australian Climate Change Science Program (which aims to improve our understanding of the causes, nature timing and consequences of climate change). To strengthen this effort, governments should ensure that there is adequate funding for world-class performance in high-priority areas, including through the ACCESS model (see Box 15.1) and investment in substantial supercomputing infrastructure"*.

In order to provide the detailed information essential for climate change planning at national, regional and local levels Australia's climate focussed supercomputer capacity needs to be increased significantly beyond that which is identified in the current upgrade path.

> Box 3 – Criticality of enhanced High Performance Scientific Computing (HPSC) for climate science
>
> Recent agreement by the Bureau of Meteorology and the National Computing Infrastructure initiative (hosted by ANU) to issue joint tenders for their impending HPSC upgrades, with additional investment from CSIRO, is a move towards interoperability for climate simulation that is a welcome advance on the historical lack of compatibility between the agency and academic HPSC systems devoted to climate. NCI has received $26m in funding through NCRIS platforms for collaboration and a significant 'Team Australia' benefit in enhanced computing capability will result. However, this is only the first of three steps necessary to guarantee success of this Framework. The second is a significant additional investment in the next two to three years to upgrade the proposed HPSC capability towards the power currently available to leading climate modelling groups in countries such as the UK (Hadley Centre) and France (IPSL). The third is a national commitment to develop an HPSC upgrade strategy that will yield the next required HPSC enhancement, conceivably a massively enlarged single national facility for climate simulation having truly cross-institutional support. In this context it is imperative to recognise that the current upgrade paths for 3 years hence slated for the separate Bureau and NCI systems are incapable of delivering the necessary computer power for the suite of models and applications shown in Figure 3. This is a make-or-break issue for the success of the Framework.

3.4 Implementation

National coordination

Australia must make the most of the available climate change science resources. Skilled scientists are distributed across several institutions, including block-funded agencies such as CSIRO and the Bureau of Meteorology, universities, and some state government research agencies. Major national research infrastructure is provided through initiatives managed by the Department of Innovation, Industry, Science and Research. In many instances the climate change science community must share this infrastructure with researchers in other fields.

More effective mechanisms are needed to coordinate work across these institutions to:

- harness the best available science talent to work on national climate change science priorities;
- use scarce resources, such as large-scale infrastructure, more efficiently;
- foster the development of new talent; and
- maintain our competitiveness and encourage innovative research.

A model for coordinating Australian climate change science should have the following features:

1. A single integrated program to address national climate change science priorities over the coming decade and beyond, with agreed targets and outcomes.

2. Revised funding and institutional arrangements to enable collaboration and sharing of resources from across institutions to build multi-institutional teams. This would include arrangements to enrich the training of PhD students and postdoctoral workers by allowing them to work with research leaders from a

range of institutions, with attention to development of career paths that lead to retention of talented individuals and renewal of Australia's human resource base in climate science.

3. Resources allocated on the basis of demonstrated need and scientific merit, ensuring that the best available scientists are using the most effective research approaches to address national priorities.

4. Long-term institutional stability for core infrastructure. In addition to major items of physical infrastructure such as supercomputing facilities, fixed observing systems and major deployable platforms such as research vessels, core assets include developed products such as the components and overall 'soft' infrastructure supporting climate system models.

5. "Interoperability" between agency and university high performance computing platforms.

6. Scope for 'blue skies' research. Blue-skies – or curiosity-driven – research is essential to generate new ideas, attract high quality scientists and train new scientists. While most resources should be directed to research targeted at national priorities, some provision must be made for 'blue skies' work in which the power of Australian intellectual creativity can be harnessed.

7. Administratively efficient procedures supporting collaborative activities and multi-party teams irrespective of the home institution of researchers.

8. Regular reviews against national objectives and milestones.

A proposed national strategy

A National Climate Change Science strategy with the following features would be best placed to provide necessary national direction and coordination of climate change research efforts.

- A high level coordination group comprising major funding bodies, key research organisations and senior scientists and chaired by the Chief Scientist. The coordination group will develop and oversee execution of an implementation plan for this Framework.
- The implementation plan will draw on the resources of all relevant organisations. Where necessary, the high level coordination group will facilitate formation of cross-institutional teams to advance key elements of climate change science.
- The Chief Scientist will report annually to the Minister for Climate Change and Water and the Minister for Innovation Industry Science and Research on progress in implementing this Framework.
- The Department of Climate Change will establish a mechanism to liaise with States and Territories and other stakeholders on climate change science, with a particular emphasis on ensuring the national program delivers useful information about likely future climate change.

The implementation plan will ensure effective engagement of universities. This could include promoting 'sharing' of PhD students and post-doctoral workers between institutions, exchange of staff between institutions and cross-institutional research. The implementation plan will identify research areas where universities have a lead role. This will provide a pathway for career development from postgraduate student, to postdoctoral fellow, to agency scientist that would make Australia a preferred destination for individuals interested in training to become climate scientists. This will help position Australia to attract or retain the brightest students in the 'global war for talent'.

Some mechanisms to coordinate elements of climate change research are already in place. CSIRO and the Bureau of Meteorology have formed the Centre for Australian Weather and Climate Research (CAWCR), which conducts leading work on climate modelling and process studies. In addition, the Antarctic Climate and Ecosystem Cooperative Research Centre has emerged as a mechanism to coordinate climate change research in the Southern Ocean and the Antarctic.

Australian Climate Change Science would benefit from improved coordination of university research so that university researchers can contribute more effectively to a national effort. The Department of Climate Change and the Australian Research Council will develop advice on and report to the Minister for Climate Change and Water and the Minister for Innovation Industry Science and Research on options for enhanced university engagement with publicly funded research agencies in the area of climate change.

Investment

Over the past decade, Australia has performed superbly in climate change science on a relatively modest national budget. However the demographics of the workforce and requirements for strengthened research infrastructure present a compelling case for renewal if Australia is to maintain its current capability, let alone address the growing calls for enhanced climate science information from the adaptation, mitigation and broader policy communities. In other words, the breadth and complexity of the science now needed to support Australia's national and global response to climate change are such that leveraging all available resources to deliver the national initiative is required.

There is clear scope for maximising collaboration and the distribution of funds for climate change science under a national Framework. The report of the PMSEIC working group on Climate Change in Australia: Regional Impacts and Adaptation *June 2007* recommended that:

> *The barriers within and between current funding schemes should be removed in order to enhance collaborative multidisciplinary research.*

The working group based this recommendation on observations that some current funding sources constrain the breadth of science that can be undertaken, the parties who may access the funding, and the parties who may collaborate under such schemes. The impact of this is often that research teams can be a reflection of the best representatives from eligible institutions, rather than the best to undertake specific research.

4. Benefit to Australia

The acute and diabolical problem of climate change facing Australia requires a national response. In that context, the National Framework for Climate Change Science sets a vision for Australian climate change science that will deliver the science needed for the future health and productivity of our nation in the context of climate change.

The scope of work and national arrangements envisaged under this Framework represent a step change to deliver on that vision. There are five major elements to this step change.

First, there is the move from physical climate simulation to full climate system simulation. This will capture all the feedbacks between the physical, chemical and biological systems not captured in previous IPCC assessments, but which are essential to make climate simulations more accurate.

Second, there is the move to support global policy analysis through developing an Australian Integrated Assessment Model – a new capability for Australia – that will couple climate simulations dynamically to economic and social models.

Third, the Framework will provide for the national coordination of all of Australia's climate change science intellect, through a new, high level nationally representative climate change Science coordination group chaired by the Chief Scientist that will provide advice on national priorities, oversee the development of an implementation plan and report to government on progress. The Framework will bring the university sector's capabilities into the national Framework as co-contributors with government agencies to deliver the nation's long-term, strategic climate science needs.

Fourth, the coordination of the university sector and government science agencies will ensure that the necessary human capital renewal and its expansion as needed to deliver the Framework goals is a key element.

Fifth, the Framework also provides a coherent rationale and maximises opportunities for co-investment in landmark infrastructure (e.g. research vessel, and high performance scientific computing) needed to deliver a fully functional and effective national climate science capability.

The benefits of this Framework will be self-evident a decade from now. Australia will be at the forefront of informed global debate on global measures to combat climate change. Australia will be a world leader in adapting to the unavoidable consequences of climate change and will be sharing that expertise with the countries of our region. Australia will have in place mitigation policies and practices that are acknowledged as world's best practice.

These outcomes will require a national commitment, the breadth and depth of which has not before been realised – central to their achievement will be the early adoption of this National Framework on Climate Change Science.

Appendix:

1. Recent Reviews that support the National Framework approach

Australian Climate Change Research: Perspectives on Successes, Challenges and Future Directions, S. Solomon and W. Steffen, Department of Climate Change (2007), 16 pp.

Strategic Roadmap for Australian Research Infrastructure, Department of Innovation, Industry, Science and Research (2008), pp 5, 21, 27-28, 33-34.

The Garnaut Climate Change Review Final Report, R. Garnaut, Cambridge University Press, Australia (2008), pp xxxiii, xli, 318, Ch15, 366-368.

Venturous Australia, building strength in innovation, Cutler and Company Pty Ltd (2008), Ch5, 45-62, Ch11, pp144.