



# AUSTRALIAN CLIMATE CHANGE SCIENCE PROGRAMME

STRATEGIC RESEARCH AGENDA

2004–2008



**Australian Government**  
Department of the  
Environment and Heritage  
Australian Greenhouse Office



**Australian Government**  
Bureau of Meteorology



**Australian Government**

**Department of the  
Environment and Heritage  
Australian Greenhouse Office**

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## MINISTER'S FOREWORD



The current four year Australian Climate Change Science Programme (2004 to 2008) is creating essential information to assist Governments, business and the community to understand what our future holds in terms of climate change.

Through its contribution of more than \$30 million, the Australian Government is investing strongly in this research effort.

This initiative is part of the Australian Government's \$1.8 billion climate change strategy through which we are taking action to reduce our domestic greenhouse gas emissions, working to develop an effective global response to climate change and helping to prepare communities, industries and regions to adapt to the unavoidable impacts of climate change.

The scientific work conducted so far by Australian scientists and their counterparts around the world has demonstrated conclusively that human activity, for example burning of fossil fuels and deforestation, is changing the Earth's climate system.

However, there are still gaps in our knowledge. The Australian climate change science investment is designed to provide knowledge in key areas such as the role of the Southern Ocean in our climate, how climate change could influence the intensity of extreme weather events, and whether can we attribute observed changes in climate to the enhanced greenhouse effect.

This ongoing scientific work is helping us piece together the puzzle of climate change and its national and regional impacts – a very important task.

Our vision is to build a sound understanding of climate change and the potential impacts on the environment, the economy and society. Sound decision-making needs sound science.

This publication complements its partner publication Australian Climate Change Science Programme – Major Achievements 1989-2004.

I am delighted to recommend these publications to you as valuable resources in both documenting the significant progress made in Australian scientific research and in charting the way forward as we face the challenges of climate change in coming years.

**Senator the Hon. Ian Campbell**

**Australian Minister for the Environment and Heritage**

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## PREFACE

# The Australian Climate Change Science Programme Strategic Research Agenda

The Australian Climate Change Science Programme 2004-2008 research agenda builds on the solid base of existing research that has given Australia prominence and recognition in the global climate change science community. Achievements of the Programme since 1989 are outlined in the partner to this booklet – Australian Climate Change Science Programme – Major Achievements 1989 – 2004.

The research undertaken by the Programme is a key element of Australia's commitment under the United Nations Framework Convention on Climate Change.

The Programme will maintain Australia's world-class expertise in climate change science, and leadership of the research effort in the southern hemisphere. Without Australian research, there would be scant information about processes that are characteristic of the southern hemisphere that impact both the Australian and global climate. Northern hemisphere science is unlikely to answer some of the big questions for Australia – for example, the influence of our surrounding oceans on extreme climate events (droughts and bushfires, storms, cyclones and floods), and the cause of the 20 per cent reduction in rainfall in south-west Western Australia over the past 30 years.

The research Programme is designed to advance our understanding of these challenging questions,

and to respond to stakeholder requests for an accelerated research effort to describe the implications of climate change for industry sectors, regions and the community. The development of this research agenda has benefited from input by business and industry stakeholders as well as the climate change science community.

The Programme will support the ongoing development of a national climate modelling capacity, maintaining our world-class position. It will support Australia's standing in international forums, the development and maintenance of bilateral agreements, and the contribution of our scientists to key international processes – such as the preparation of the Fourth Assessment Report of the Intergovernmental Panel on Climate Change which will be published in 2007.

Importantly, this Programme targets policy-relevant research and will advance the frontiers of science to provide the best possible information to support decision-making on climate-related issues. The Programme underpins the capacity of governments, business and industry, and the community to understand and respond to climate change.

Advances in understanding of climate change and its likely impacts will be vital to the preparedness of Australia to respond and adapt.

## INTRODUCTION



The drivers of Australia's climate are unique. Our needs will not be serviced by northern hemisphere research

### A targeted Australian research effort

The Australian Climate Change Science Programme (ACCSP) focuses its research effort on areas of strategic and scientific importance to Australia - improving our understanding of significant climate processes in our region and addressing key questions that are unlikely to be addressed by northern hemisphere research. Because of major differences in ocean and polar influences on climate, together with uniquely Australian hydrological systems, fire regimes, soils and ecosystems, southern hemisphere climate processes differ significantly from those in the northern hemisphere. It is not in our interest to rely only on northern hemisphere research.

Australia's climate is strongly influenced by the surrounding oceans - interactions between the oceans and the atmosphere drive ocean current patterns that have a pronounced effect on the regional and global climate. El Niño and La Niña events have a strong influence on climate variability in many parts of Australia, leading to alternations between floods and prolonged droughts, especially in eastern Australia.

Currently climate models do not give a consistent indication of these phenomena, but suggest the drying associated with El Niño events may be enhanced by global warming. **One of the key questions for Australian climate change research is to understand why the 2002 El Niño event was less intense than the event of 1997, and yet the drought associated with it was more severe.** Through targeted research and enhanced climate modelling, Australia will learn more about El Niño and about the influence of the Indian and Southern oceans on climate. We will be in a better position to project more reliably the impacts of climate change in our region (see section 1.5.3 and Box 4).

Australian average temperatures have risen by 0.7°C over the last century, and in the second half of the 20th century the warming trend appears to have emerged from the background of natural variability:

- Rainfall has increased over the last 50 years over north-western and central Australia, but decreased in much of southern and eastern Australia.
- There has been a 50 per cent drop in water supply to the reservoirs supplying Perth since 1970. Near-record low water storages in much of south-eastern Australia in 2002-03 have been recorded due to low rainfall and high temperatures in the south-east since 1996.
- A combination of climate variability and the enhanced greenhouse effect is considered to be the cause of the rainfall decline in the south-west of Western Australia (IOCI 2002).
- Recent research suggests that the interaction between global warming and stratospheric ozone depletion may also be causing a southward shift of westerly rain systems.

Attribution of climate change to these and other apparent climate shifts in Australia is a major new area of research under the ACCSP (see section 1.5).

The Programme also targets another important area of research - extreme climate events. Changes in the frequency or intensity of extreme events are expected to dominate impacts of climate change. Heavy rains, floods and storm surges, possible increases in cyclone intensity and mid-latitude storms, and more severe and possibly more frequent droughts will have major social, economic and environmental consequences (see section 3).

In addition, research will target a number of scientific uncertainties identified by the IPCC Third Assessment Report - such as the magnitude and character of natural climate variability; factors controlling the ocean uptake of carbon dioxide; the timescale and likelihood of changes in the ocean thermohaline circulation; and the understanding and prediction of regional changes.

## Programme development

An independent evaluation of the Programme in 2003 highlighted areas of core scientific research that need to continue and recommended several new components. The evaluation recommendations, together with key knowledge gaps identified by the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report 2001, and the relevance of climate change research to the Australian Government's policy needs, provided a framework for subsequent discussions with science providers and stakeholders to identify research priorities.

A series of workshops with stakeholders and researchers contributed to the development of the programme. Overall, stakeholders supported an ongoing climate change science programme with the following aims:

- improving our understanding of the causes of past, present and future variations in Australian climate;
- addressing key climate science questions facing Australia that will not be answered through northern hemisphere research;

- improving our climate modelling capacity and maintaining our international stature in modelling;
- providing more reliable and comprehensive regional climate projections for Australia – including quantification of uncertainty and risk;
- maintaining our influence on/contribution to the international climate change agenda;
- enhancing recognition of Australia's high quality climate science research; and
- provision of relevant, up-to-date information to support mitigation and adaptation responses.

Through its climate change strategy, announced in 2004, the Australian Government is currently investing \$30.7 million to the Programme between 2004 and 2008.

The Programme is administered by the Australian Greenhouse Office in the Department of the Environment and Heritage. Major science providers and co-investors in the Programme are the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Bureau of Meteorology Research Centre (BMRC). The Australian Academy of Science participates by providing links to key international programmes.







## The Australian Climate Change Science Programme's vision and objectives

Programme research will improve our understanding of the causes, nature, timing and consequences of climate change for Australia and our region

### Vision

Australia empowered with the science-based knowledge to manage the risks and opportunities of climate change.

### Objectives

- **maintain** world-class expertise to ensure Australia's key science questions are answered and influence the international understanding of climate change science;
- **improve** understanding of the causes, nature, timing and consequences of climate change for Australia and our region;
- **underpin** domestic climate change policy and support targeted and effective national mitigation and adaptation action;
- **contribute** to the delivery of Australia's National Research Priorities for An Environmentally Sustainable Australia; and
- **leverage** bilateral and regional cooperation through the growing area of international science partnerships, and advance Australia's expertise and contribution to southern hemisphere climate change science.

## Major research components 2004-2008

The five research components of the Australian Climate Change Science Programme are:

1	Understanding the key drivers of climate change in the Australian region
2	A national climate modelling system
3	Climate change, climate variability and extreme events
4	Regional climate change projections
5	International research collaboration



# 1. UNDERSTANDING THE KEY DRIVERS OF CLIMATE CHANGE IN THE AUSTRALIAN REGION

## Identifying the causes of past, present and future variations of Australian climate

Research conducted through the ACCSP spans observations and analysis of oceans, the atmosphere and terrestrial environment to improve our understanding of the complex natural processes that influence climate variability and change. It includes research into:

- oceanic processes – Southern, Pacific and Indian oceans;
- sea level rise;
- the role of aerosol and clouds in climate;
- changes to carbon cycling in Australia;
- detection and attribution of climate change – understanding the causes of recent climate shifts in Australia; and
- palaeo-science, which provides historical records (ice cores, tree rings, coral cores etc) that help place the current observed changes in the atmosphere in a longer historical perspective, and provide a database against which climate models can be tested.

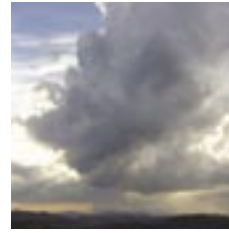
Key areas of oceanic research will include continuing investigation of the ocean's thermohaline (overturning) circulation, and major influences on Australia's climate variability such as the El Niño-Southern Oscillation, Indian Ocean Dipole and the Indonesian Throughflow.

Terrestrial observations will pave the way for more complex research into Australia's carbon dioxide budget – the patterns and behaviour of sources and sinks.

A major challenge for Australia and the international community is the detection of climate shifts and attribution to specific causes (see Box 4). A number of intriguing climate shifts in Australia and their potential causes will be investigated.

Overall this research will give us a clearer picture of the dynamics of the major drivers of the world's climate – the Antarctic atmosphere, ice and ocean systems. It will also give us a better understanding of the behaviour of our own terrestrial systems – this is essential for Australia as our systems are very different from those of the northern hemisphere. A key result will be a better understanding of the role of feedbacks in the climate system and their role in determining climate sensitivity. Feedbacks are processes in the climate system that can either amplify or dampen the system's response to changed forcings (see Box 1).





## Box 1: Climate feedbacks – affecting the magnitude, rate and patterns of change

Climate changes can be initiated by external factors forcing the climate system.

These climate forcings include natural factors such as changes in energy flux from the Sun, variations in the Earth's orbit, and volcanic eruptions, as well as human activities, such as production of greenhouse gases and aerosols, and modification of the land surface.

Over the century it is likely that forcing of the climate system by human activities will greatly exceed changes in forcing caused by natural events.

Processes in the climate system that can either amplify or dampen the system's response to changed forcings are known as feedbacks – positive or negative.

An example of a positive feedback is the melting of polar ice. As the temperature warms, polar ice retreats. Less ice means there are less reflective surfaces and the exposed land surface absorbs more heat. This accelerates further melting of the ice.

According to estimates generated by current climate models, more than half of the warming expected in response to human activities will arise from feedback mechanisms internal to the climate system, and less than half will be a direct response to external factors that directly force changes in the climate system.

Feedback processes can be grouped into three categories:

- (1) those that primarily affect the magnitude of climate change:
  - cloud, water vapour and lapse rate feedbacks
  - atmospheric chemical feedbacks – aerosols
  - biogeochemical feedbacks and the carbon cycle
  - ice albedo (reflectance) feedback;
- (2) those that primarily affect the rate or timing of climate change:
  - ocean heat uptake and circulation feedbacks; and
- (3) those that primarily affect the spatial patterns of climate change:
  - land hydrology and vegetation feedbacks
  - natural modes of climate system variability.

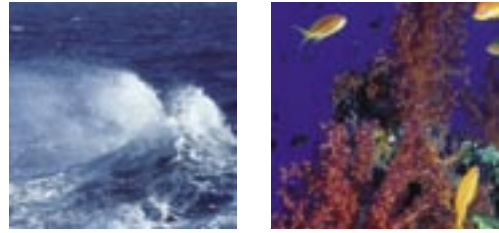
These categories are helpful for promoting public understanding of the importance of feedback processes because they translate into questions like:

**“How big or important will climate change be?” “How rapidly will our climate change?” and “How will climate change in my region?”**

The ACCSP will be supporting research into a number of feedback processes that could affect Australia's climate. Other feedback processes such as ice reflectivity are being addressed through related research by the Antarctic Climate and Ecosystems CRC.

Source: National Academy of Sciences, [www.nap.edu/catalog/10850.html](http://www.nap.edu/catalog/10850.html)

## 1.1 Oceanic processes - the role of the oceans in climate



### Australia is a leader in Southern Ocean research

Australian research has led to a better understanding of ocean processes and their influence on climate. We are taking the lead in the design, coordination and implementation of research in ocean regions relevant to Australia - the Indian, South Pacific and Southern oceans.

Our research has brought scientists and research ships into these waters and has attracted considerable international investment, substantially enhancing the scale of what can be achieved.

Australia is located between the Southern Ocean and the Indonesian Throughflow - the two primary means of water exchange between the major ocean basins (Figure 1). The flow through these passages transforms the ocean circulation from a basin-scale to a truly global pattern, with profound influences on the Earth's climate. These regions are of particular interest not only because of the impact they have on our climate but also the potential of Australian research in these areas to significantly improve the accuracy of climate models to represent ocean climate processes.

This research will significantly reduce uncertainties in climate predictions and provide a firmer basis for the assessment of the likely impact of climate change on marine ecosystems and the identification of sustainable management options.

The oceans of the world play a fundamental role in the climate system – storing excess heat and anthropogenic carbon dioxide

Over the past 50 years, the oceans have absorbed about 90 per cent of the excess heat trapped by elevated greenhouse gases in the atmosphere and have sequestered about 30 per cent of the anthropogenic carbon dioxide emitted into the atmosphere.

The ocean is the primary long-term sink for atmospheric carbon dioxide and helps control the rate of carbon dioxide increase in the atmosphere, and therefore the rate of global warming. The rate of future climate change will depend on the role the oceans play in absorbing the build-up of heat and carbon in the atmosphere.

Heat absorbed by the ocean in one location may be carried thousands of kilometres before being released into the atmosphere. This release of heat drives motions in the atmosphere that determine the temperature and rainfall patterns that make up our climate.

The evolving climate may alter the rate of heat uptake by the ocean through increased thermal stratification of the ocean, or through the effect of changes in surface precipitation and evaporation on ocean salinity and density.

Observations and analysis of the exchange of heat and carbon dioxide at the air-sea interface, temperature and salinity distribution in the global ocean and the air-sea fluxes of heat and freshwater will contribute to improvements in climate models. Activities will involve satellites, the Argo profiling floats, in situ observation networks and ship-based measurement of the upper and deep ocean, particularly areas in which bottom water formation occurs.

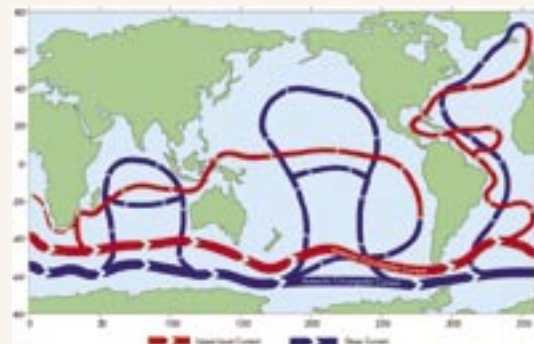


Figure 1: Major ocean currents - Antarctic Circumpolar Current and the thermohaline circulation.

### 1.1.1 The Southern Ocean – a key driver of the Earth’s climate

**This research focuses on the circulation of the Southern Ocean and its interactions with the atmosphere and sea ice – which are critical for estimating the timing and magnitude of climate change.**

The Southern Ocean drives climate in three ways. First, the strong flow of the Antarctic Circumpolar Current from west to east around Antarctica connects the Pacific, Indian and Atlantic ocean basins and their currents (Figure 2). The resulting global circulation redistributes heat and other properties, which influence patterns of temperature and rainfall.

Second, the Southern Ocean is a source of intermediate and deep bottom water that renews the world’s oceans (Antarctic Bottom Water). The cooling of the ocean and the formation of sea ice during winter increase the density of the water, which sinks from the sea surface into the deep sea. This dense bottom water, produced between 60°S and the Antarctic Shelf, influences ocean circulation, hence controlling the distribution of the physical and chemical properties of the deep ocean – not just in the Southern Ocean but throughout the world’s oceans.

Third, at the sea surface, when water cools it exchanges gases such as oxygen and carbon dioxide with the atmosphere. As a result, sinking water efficiently transfers heat, fresh water and gases into the deep ocean four to five kilometres beneath the sea surface. Biological processes also play a role here, by influencing the content of carbon dioxide in the surface water.

### 1.1.2 Antarctic Bottom Water and the thermohaline circulation

**A major goal of this research is to improve understanding of Southern Ocean processes, to monitor the state of the Southern Ocean and look for evidence as to whether the thermohaline circulation is weakening.**

The Southern Ocean accounts for about half the formation of dense bottom water that ‘ventilates’ the deep ocean, which is an essential component of the global thermohaline (overturning) circulation. The thermohaline circulation transports heat around the globe and controls how much heat and carbon dioxide is stored in the ocean. The upwelling branch of the thermohaline circulation supplies nutrients that support biological productivity; the sinking branch supplies oxygen to the deep ocean, sequesters carbon dioxide and carries ‘excess’ nutrients northward to support 75 per cent of global primary production. Changes to atmospheric composition and behaviour can affect primary ocean currents, sea ice and other biophysical systems.

The deepest layers of the ocean were considered to be very stable in their properties and current patterns. However, observations by programme scientists in early 2005 show that the deep waters of the Southern Ocean are cooler and less salty than they were 10 years ago (Figure 3). The cooler and fresher water near the sea floor indicates a change in the sources of dense bottom water supplying the basin. There are two main sources of the bottom water in the region – a salty variety from the Ross Sea and a fresher variety formed near the Mertz Glacier in Antarctica. These new observations show that the dense water produced around the periphery of Antarctica is capable of rapid and widespread change.



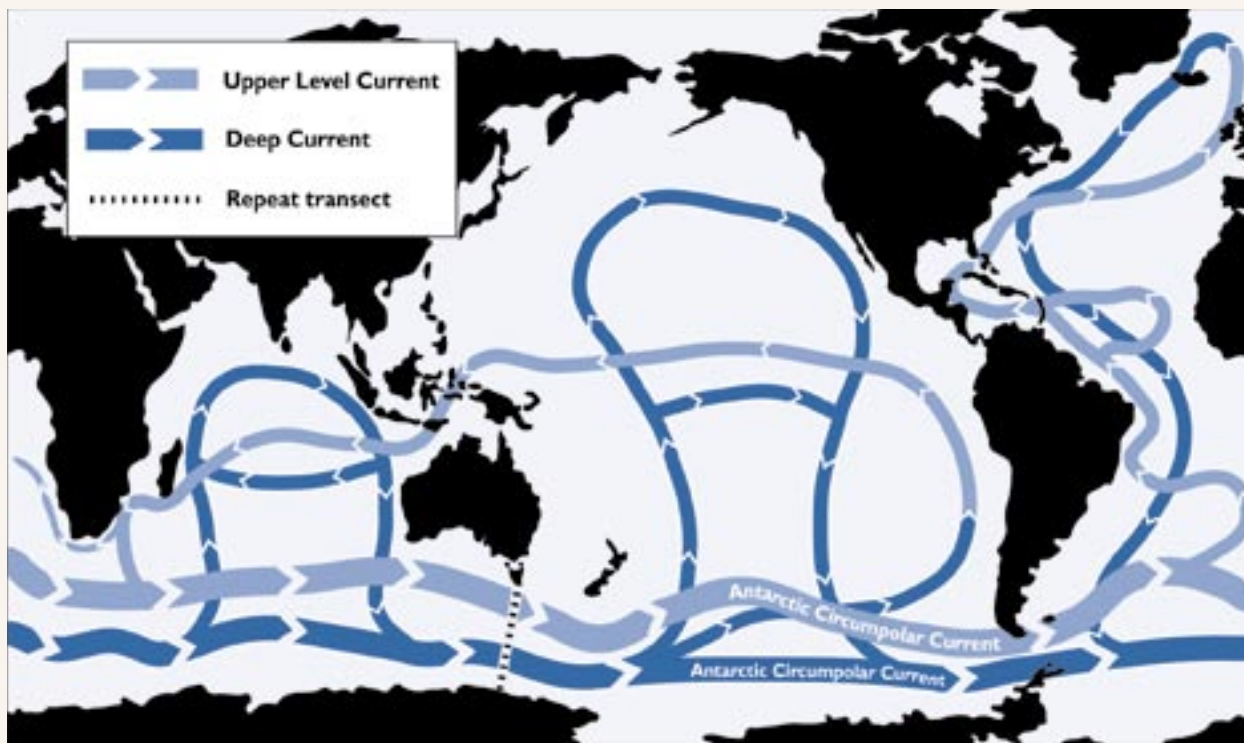


Figure 2: Schematic diagram of the global ocean circulation pathways, the 'conveyor' belt (CSIRO).

Ocean circulation has a major influence on global climate, so it is critical that we understand why this is happening and why it is happening so quickly.

Many climate change model projections suggest the Southern Ocean thermohaline circulation may weaken in the future. Climate models have yet to include the possible effects of significant freshwater input from melting ice sheets and glaciers. This might enhance the weakening of the thermohaline circulation. Further examination of this low probability, high impact event, is essential (see Box 5: Abrupt climate change)

### 1.1.3 The Southern Ocean carbon sink – detecting change

The region around Australia has a significant impact on the ocean's capacity for uptake and storage of carbon dioxide

Research aims to identify key processes regulating the uptake of carbon dioxide by the ocean, and to investigate the potential for change to storage and uptake in the Australian sector of the Southern Ocean.

The Southern Ocean is one the most significant regions on Earth for regulating the build-up of anthropogenic carbon dioxide in the atmosphere.

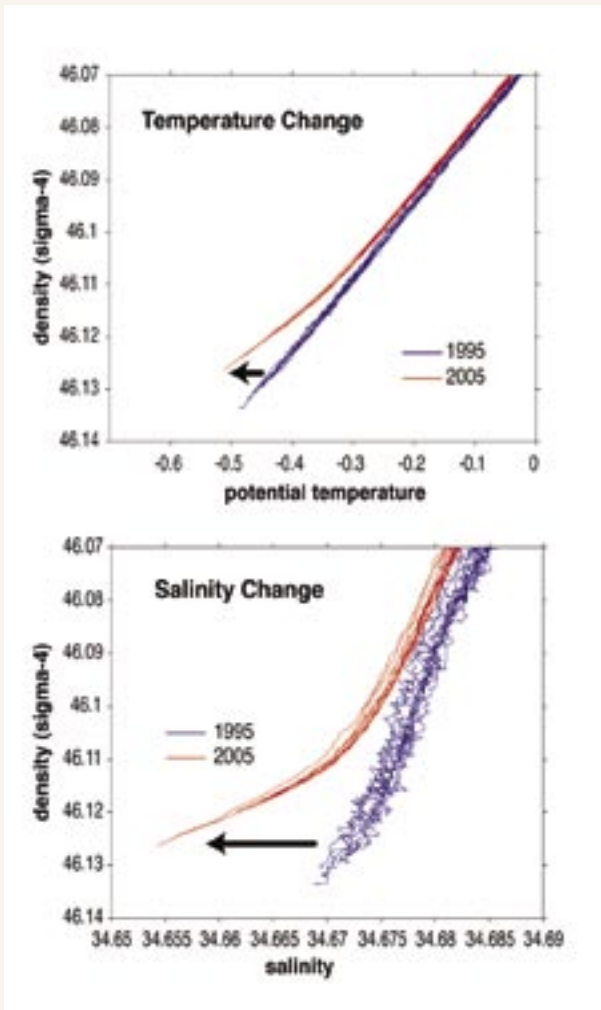


Figure 3: Oceanographic measurements in 2005 (red lines) show that the dense Antarctic Bottom Water is significantly cooler and fresher now than observed 10 years ago (blue lines). Potential temperature is the temperature of sea water after removing the effect of pressure (very close to 'normal' temperature).

About 40 per cent of the ocean inventory of anthropogenic carbon dioxide resides in the Southern Ocean and in the sub-Antarctic including the subtropical waters on its northern boundary. The carbon uptake is high in the Southern Ocean and the thermohaline circulation is an important regulator of the ocean's uptake rate.

Through the ACCSP and collaborative research with CSIRO and the Antarctic Climate and Ecosystems CRC, we have a better understanding of the capacity of the sub-Antarctic and waters south of Australia to store carbon dioxide. Previously we had to rely on models to identify how the ocean was storing carbon. We now have storage values based on ocean carbon measurements.

There are a number of climate change feedbacks (see Box 1) that may alter oceanic carbon storage in the future, and the Southern Ocean is considered one of the most sensitive regions.

Another major issue in ocean uptake of carbon dioxide is acidification. Observations show that carbon storage is leading to the acidification of surface waters with potentially serious ecological consequences. The oceans currently have a pH of about 8. Experts consider that this could drop to pH 7.4 by 2100 if global emissions of carbon dioxide continue on current trends.

This pH is probably lower than has been experienced for hundreds of millennia and, critically, this rate of change is probably one hundred times greater than at any time over this period.

Increasing acidification could affect corals and other marine organisms whose skeletal parts are composed of calcium carbonate because it reduces the availability of carbonate ions in the water for them to utilise.



Quantifying the ocean's storage and uptake of carbon and understanding how the process is evolving are important for climate projections and for assessing the biogeochemical responses.



Figure 4: Measuring carbon dioxide in the Southern Ocean – laboratory on board the French Antarctic vessel L'Astrolabe – a collaborative programme with Australia (Peter Ellis).



Figure 5: Corals and other marine species that use calcium carbonate to build their skeletons and shells could be affected by changes in ocean pH.

#### 1.1.4 Robots measuring oceanic changes in the Australian region

**This project uses data from the Argo float array in our region and historical data – temperature and salinity – to explore broad-scale ocean climate change and variability.**

The majority of the climate system's total heat gain over the past 50 years has been taken up by the oceans. The distribution of this change in heat content is complex, reflecting changes in both surface heating rates and wind changes.

Just as in the atmosphere and for terrestrial impacts, the regional detail of changes is a key to understanding and predicting impacts of climate change.

New observing systems, such as the robotic Argo floats, allow oceanic changes to be monitored regionally and globally for the first time. Efforts to find and compile useful historical ocean data are allowing past ocean climate change to be mapped and used to test climate model predictions.

Australia is a founding contributor to Argo, a novel method of collecting information from the upper ocean using robotic floats. The floats drift at depths between 1000 and 2000m. Every 10 days each float ascends to the surface measuring temperature and salinity. These data and the float's position are transmitted to satellites. The float then dives and starts a new cycle. Argo data complement other observations obtained from ships, moored instruments and earth observing satellites. Argo data are used in operational ocean and climate analysis and forecasting and in a wide range of oceanographic and climate research.



Figure 6: An Argo float (CSIRO).



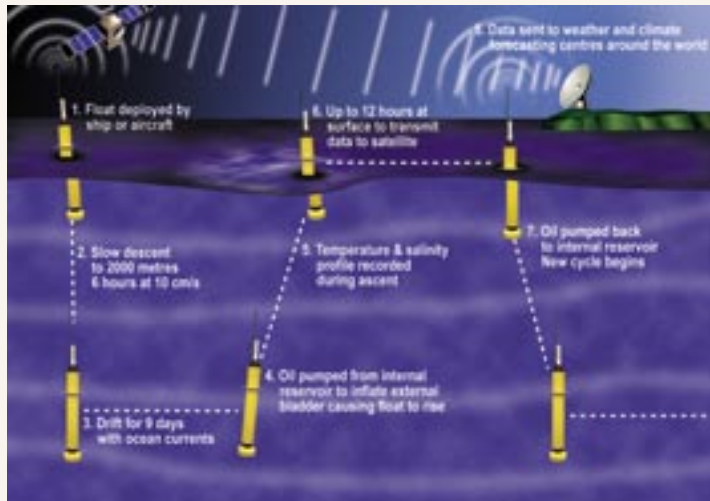


Figure 7: Schematic of an Argo float cycle (CSIRO).

The first 10 Argo floats launched in 1999 were Australian. By late 2005 through international efforts, over 2000 active floats were in place and the array should be complete in 2007. Australia has deployed 51 floats in the Indian, Pacific and Southern oceans, with funds to deploy 30 per year in the near term. To maintain coverage around Australia about 60 floats per year are needed. Maintaining and expanding the Argo array is a key objective of the ACCSP.

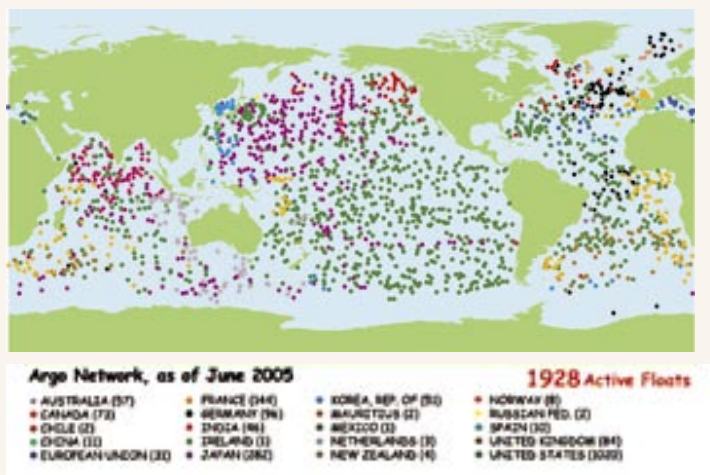


Figure 8: Deployment of Argo floats in the world's oceans as of June 2005 (CSIRO).

### 1.1.5 Major regional currents - dynamics and variability

Confidence in predictions and scenarios of climate change rely on correct simulation of many climate processes, including the drivers of regional ocean currents and their variability. Long records of ocean flows are required to understand processes controlling variability and the way in which ocean currents redistribute heat.

This research builds on past work to measure and understand drivers of the long-term variability of our largest regional ocean currents systems - the **Antarctic Circumpolar Current**, the **East Australian Current**, and the **Indonesian Throughflow-Leeuwin Current** system. What we learn from these observations will be used to examine the adequacy of low-resolution climate model simulations, and improve the accuracy of predictions for marine climate impact work.

#### Antarctic Circumpolar Current - the world's largest current

The Antarctic Circumpolar Current (ACC) is the largest current in the world and the most important current in the Southern Ocean. It is the only current that flows completely around the globe without being blocked by land - connecting the Atlantic, Pacific and Indian oceans to form a global network of currents that redistributes heat around the world and influences the climate of much of the Earth (Figure 9). The stability of the thermohaline circulation, of which the ACC is part, is a major focus of oceans research.

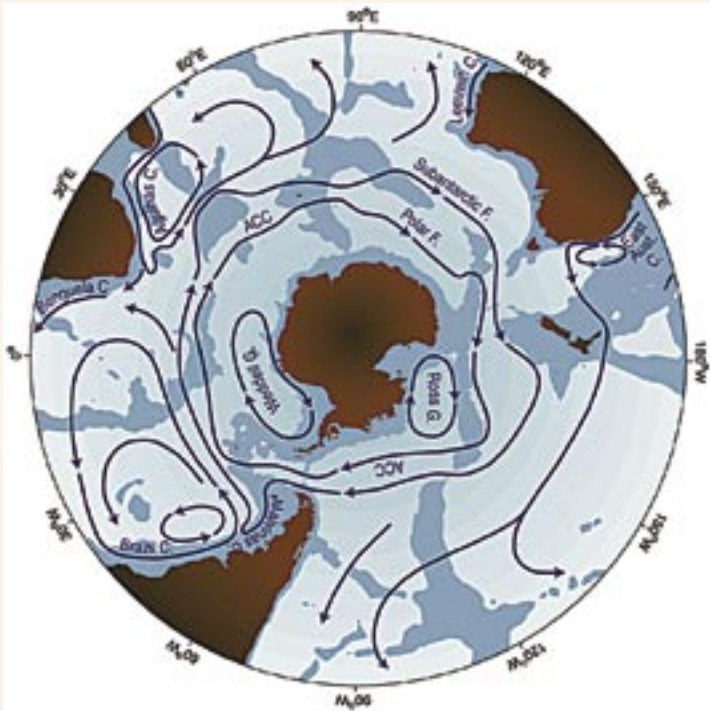


Figure 9: The Antarctic Circumpolar Current links the world's ocean basins (CSIRO).

### The Indonesian Throughflow - an inter-ocean highway

**This research investigates fluctuations in the flow of warm waters from the western Pacific Ocean draining through the Indonesian Archipelago into the Indian Ocean north of Australia and how they influence rainfall across southern Australia and Indonesia.**

The atmosphere is very sensitive to the distribution of warm waters near the equator. In our region two large warm water 'pools' exist - in the Western Pacific Ocean and Eastern Indian Ocean. The Indonesian Throughflow comprises a series of currents that transfer warm, low salinity waters from the tropical Western Pacific through the Indonesian seas into the South Indian Ocean (Figure 10). The Throughflow is the only warm water connection between the major ocean basins, and ocean

temperatures north of the continent are closely linked to Australian climate variability.

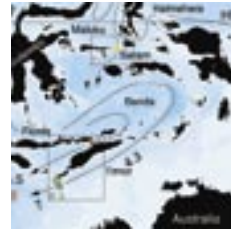
Most of the Throughflow water feeds the South Equatorial Current, the dominant flow across the South Indian Ocean, with a shallow component flowing back eastward to feed the Leeuwin Current. The Leeuwin Current transports warm water south along the Western Australian coastline, profoundly influencing ocean conditions and coastal climate.

The ACCSP supports research into fluctuations in the flow of warm waters from the western Pacific Ocean draining through the Indonesian Archipelago into the Indian Ocean north of Australia and how they influence rainfall across southern Australia and Indonesia.

Sub-surface ocean monitoring equipment has been moored at strategic 'choke' points across the entry of the currents into Indonesia waters, and their exit to the Indian Ocean through Lombok and Ombai Straits and the Timor Passage. The array of tidal gauges and ocean moorings measure currents, pressures, temperature and salinity to provide a record of changing conditions. The data collected will be compared with simple models and computer simulations of the tropical



Figure 10: The Indonesian Throughflow and Leeuwin Current.



oceans, and the way the oceans then interact with the atmosphere.

Over the next three years we hope to understand how the two 'pools' of warm water interact, and the variations that occur in the flow of currents, including any effects of El Niño and La Niña events. Studies of the exchange of warm, low salinity water between the Pacific and Indian oceans via the Indonesian Throughflow will yield critical information on how these two pools of warm water in our region interact. Improved climate predictions will benefit many people living in areas affected by El Niño/La Niña and the Asian-Australian Monsoon.

**East Australian Current – a key driver of large regional and seasonal shifts in biological production**

**This research aims to determine the variability in the large-scale ocean-atmosphere carbon cycle and define the biological and physical mechanisms driving the variability. The outcomes will assist in assessing the biogeochemical response to changed climatic conditions and the validation of biogeochemical models of Australian regional seas.**

The air-sea exchange of carbon and the sensitivity of associated biogeochemical cycles to changed climatic conditions are unknown for almost all of Australia's regional seas. The Tasman Sea is a major transition zone between warm and nutrient-poor subtropical waters and relatively cool and nutrient-rich waters of the sub-Antarctic zone.

Satellite images indicate that the East Australian Current system has a profound influence on the biogeochemistry of the Tasman Sea. Changes in upper-ocean mixing and nutrient concentrations and interactions with the East Australian Current appear to drive large regional and seasonal shifts

in biological production and related air-sea carbon fluxes that characterise biogeochemical cycling.

Analysing recent data from a network of Argo floats (Figure 8), Australian, US and New Zealand scientists have detected a 20 per cent increase in the speed of a key South Pacific current over the past 10 years. This South Pacific sub-tropical circular current influences the East Australian Current. As well as moving faster, it has warmed by up to 0.25°C and risen in height by 12 cm at its centre.

The warming of the current could take nutrient-poor warmer water further south along Australia's east coast, which could lead to a decline in fisheries and aid the spread of exotic marine pests. The most likely cause of the increased spin of the current is the shift southwards of a westerly wind pattern known as the southern annular mode. This wind shift may mean winter rainstorms would bypass southern Australia (see section 3.2).



Figure 11: On board a research vessel at sea (CSIRO).



## 1.2 Global and regional sea level rise



86 per cent of Australia's population lives in the coastal zone

“How fast is sea level rising?”, “What are the causes?” and “What are the implications for the future?” are key questions requiring answers.

Eighty-six per cent of Australia's population lives in the coastal zone. The impacts of climate change in the coastal zone will most likely be felt through an increase in the frequency and intensity of extreme weather events, inundation and coastal erosion.

Robust projections of sea level rise and the frequency and intensity of extreme events are vital information for the millions of Australians living in the coastal zone. For these projections to be of value in coastal planning and in minimising



Figure 12: Property in coastal zones is at risk from storm surge and sea level rise (Beach Protection Authority, Queensland).

damage to coastal infrastructure and the loss of life, they must be based on sound understanding of the causes of sea level rises and the drivers of extreme events.

In the IPCC Third assessment Report 2001, researchers did not have an accurate quantitative estimate or an adequate explanation for observed 20th century sea level rise. Estimates of 20th century sea level rise based on historical tide gauge data range from about 1 mm/yr to 2 mm/yr. One of the difficulties in estimating 20th

### Box 2: Australian Baseline Sea Level Monitoring Project

The National Tidal Facility, now part of the Bureau of Meteorology, provides timely, updated information about sea level around Australia and the South Pacific. With support from the Programme, the centre operates and maintains an array of sea level monitoring instruments in representative locations (Figure 13). The quality controlled data is collected and used to verify and understand sea level changes in the Australian region.

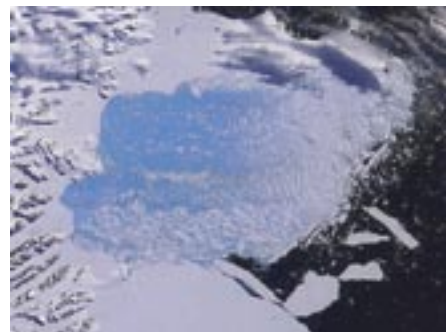
Figure 13: Map showing the Australian Baseline Sea Level Monitoring array.



Figure 14: It is estimated that acceleration of glaciers after the collapse of the Larsen B ice shelf in 2002 increased global sea level by 4 per cent (NASA).

- Melting of an ice shelf does not directly raise sea level
- However ice shelves seem to buttress flow of glaciers
- An increase in flow of glaciers does raise sea level
- Acceleration of glaciers after collapse of Larsen B increased global sea level rise by 4%

Larsen B Ice Shelf Collapse, Feb./Mar. 2002



century sea level rise is the poor distribution of tide gauges, particularly those with long records. Satellite altimeter data of the required accuracy for estimating global sea level rise for most (65S to 65N) of the global ocean has only been available since 1993 with the launch of the TOPEX/Poseidon satellite and its successor, Jason.

Sea level change is highly variable both spatially and temporally. In some regions rates are five times higher than the global mean, while in other regions sea levels are falling. Programme scientists are trying to understand whether the recent increase indicates an accelerating trend or whether it is associated with variability on a decadal timescale.

There is a range of interconnecting factors that influence sea level. Increased concentrations of atmospheric greenhouse gases and volcanic eruptions, affect the heat content of the oceans causing thermal expansion. Ocean thermal expansion is thought to be one of the main components of sea level rise during the 20th century and is expected to make the largest contribution during the 21st century. Research aims to gain reliable estimates of regional and global thermal expansion using historical and modern data sets. Melting of land based glaciers would also contribute to sea level rise (Figure 14).

Past projections of ocean thermal expansion, using a range of climate models, have shown a lack of consistency between models and produced very different regional patterns of sea level rise. The reasons for these differences are not well understood. Research will focus on reducing the uncertainties surrounding ocean thermal expansion and historical and projected global and regional sea level rise.

Research scientists have shown that volcanoes significantly influence sea level rise (see Australian Climate Change Science Programme: Major Achievements 1989-2004). Quantifying this impact is important to understanding climate and sea level variability, with important consequences for the interpretation of the observational record.

The mass of the oceans, hence sea level, can be increased through an influx of water from glaciers, ice caps and ice sheets. Scientists consider the contribution of water stored on land in reservoirs and as groundwater to be significant, however this is an area of much uncertainty.

## 1.3 Atmospheric research – aerosol and cloud feedbacks

Are aerosols (airborne particles) and clouds amplifying or dampening climate change?

We need to understand the physical and chemical processing of aerosols in the atmosphere, the dependence of these processes on climate, and the influence of climate-chemical interactions on the optical properties of aerosols. A more complete understanding of the emissions, atmospheric burden and interactions of carbonaceous and other aerosols with clouds and the hydrologic cycle needs to be developed.

**This research aims to understand the effects of aerosols and clouds on Australian climate and develop Australian aerosol modules for climate models. It will assess the role of Australian aerosols in global ‘dimming’ – is global dimming confined to the northern hemisphere, and what are the implications for the southern hemisphere and Australia?**

### 1.3.1 Effects of aerosols on climate

Aerosols are fine airborne particles of carbon, ash and sulfur compounds that reflect back the heat of the sun. Australia’s two major continental aerosol types are mineral dust generated by wind on arid soils and carbonaceous particles from burning vegetation in the tropics.

The effects of aerosols on climate are complex because they:

- can have a direct effect on the transmission of sunlight through the Earth’s atmosphere;
- can indirectly cause the optical properties of clouds to vary depending on the abundance of aerosol particles;

- can indirectly change the lifetime of individual clouds and their propensity to deliver rain; and
- vary in physical/chemical composition and spatial/temporal distribution.

Some research suggests that aerosols are the likely causes of ‘global dimming’ and they also affect the nature of clouds, which are also likely contributors. Other candidates being considered are changes in clouds and water vapour due to greenhouse warming, and major volcanic eruptions.

There is evidence that sunlight at the Earth’s surface declined by about 20 per cent per decade from the 1950s to the 1980s. The ‘dimming’ was fairly widespread but there is no evidence of dimming over Australia or New Zealand. The effects of aerosols are strongest in highly polluted regions of the northern hemisphere, which could explain why a reduction of sunlight has not been measured in Australia.



Figure 15: Dust storm 2002.

There has been some recovery of solar radiation since the 1990s. This recovery is most likely due to the reduction of aerosols and resulting improvement in air quality in the northern hemisphere (especially Europe, North America and Japan) since the 1980s.

It is well known that the regional cooling effect of aerosols has partly offset global warming due to greenhouse gases. Many scientists are concerned



Anthropogenic and natural forcing of the climate for the year 2000 relative to 1750.

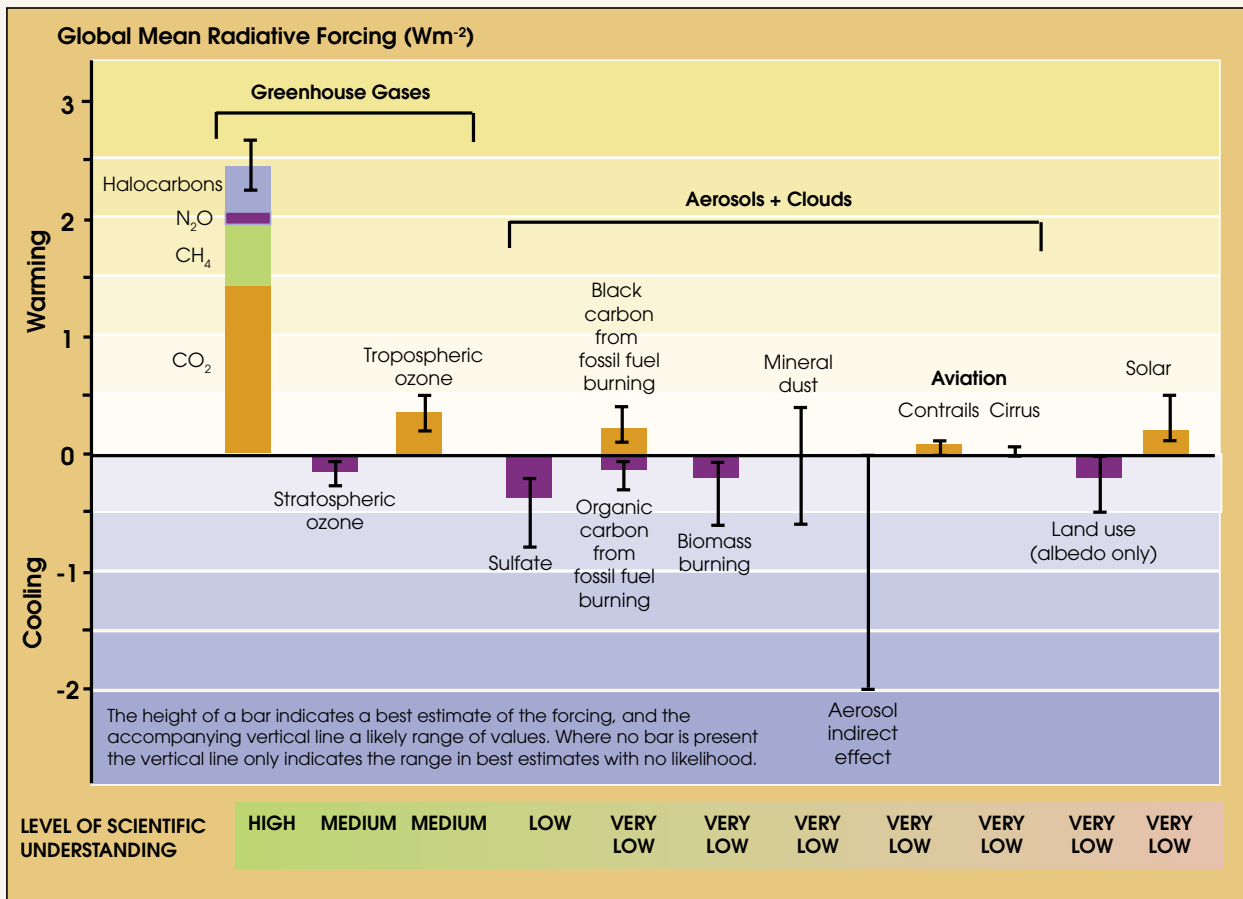


Figure 16: Global annual-mean radiative forcings (Wm<sup>-2</sup>) due to a number of agents for the period from pre-industrial (1750) to the late 1990s (IPCC 2001).

that the full effects of global warming are yet to be felt, and could be worse than currently estimated.

There is still a great deal to be learnt about aerosols. Large uncertainties still exist in the magnitude of indirect aerosol effects on cloud properties. Also, some aerosols (such as black carbon) absorb sunlight instead of reflecting it, so these aerosols tend to warm the air, even though they reduce the amount of sunlight reaching the surface. In other words, some aerosols have a warming effect on climate, even though they contribute to dimming. This complex picture is shown in the bar chart from the 2001 assessment of the IPCC (Figure 16). Compounds above the line contribute

to warming, while compounds below the line have a cooling effect. Our understanding of the impact of greenhouse gases is sound, however, we have much to learn about the effects of aerosols and clouds.

Programme researchers are undertaking research into the effects of aerosols and clouds on climate and incorporating these effects in climate models.

There are three measuring stations in the tropics (Lake Argyle, Jabiru and Darwin), one in the arid zone (Tinga Tingana in South Australia) and one in Canberra. The Canberra station was of great value in characterising the smoke emissions from the



bushfires of January 2003. An additional arid zone station is to be deployed near Birdsville, adjacent to a major source region of the Simpson Desert.

The results will have a number of environmental applications including:

- development of aerosol modules for climate models, tuned to Australian aerosol types rather than assuming 'one size fits all';
- analysis of the increasing trend in dust emissions in central Australia as a possible climate signal; and
- assessment of the role of Australian aerosol in the global dimming and brightening debate, specifically aimed at the question of whether this phenomenon is confined to the northern hemisphere, and the implications for the southern hemisphere and Australian region.

### 1.3.2 Clouds – cooling and warming

**This research will increase our understanding of climate feedback processes, such as those related to clouds.**

Cloud feedback is one of the key uncertainties in the projection of future climates, and is responsible for a large fraction of the model-to-model in climate sensitivity. It is not known whether cloud feedback will increase or decrease global warming, let alone its magnitude.

Clouds can reflect sunlight away from the Earth's surface and cause it to be cooler than it otherwise would be. They also trap heat radiation that is emitted from the Earth's surface, absorbing it in the atmosphere. Water is transported from the Earth's surface into the atmosphere, where complex physical processes cause the formation of droplets that may or may not fall as rain or snow. This condensation releases energy that further drives atmospheric mixing.

Clouds are formed in many different ways related to the regional availability of water, the topography of the land, and to the availability of nuclei on to which condensation can occur. Given their importance in the climate system it is essential that we understand both how clouds form and interact with the system as a whole, and how these complex processes themselves may change as greenhouse warming continues.

Increased physical understanding of climate feedback processes, such as those related to clouds, are critical tasks for reducing uncertainties in projecting future climate.

Figure 17: Smoke from forest fires (CSIRO).



## 1.4 Terrestrial carbon cycle – a focus on the Australian biosphere



Recent research suggests global CO<sub>2</sub> sinks will saturate, and possibly turn into a net source under some conditions

The carbon cycle is potentially a significant climate 'feedback'. Research aims to provide a more comprehensive understanding of carbon sources and sinks in the Australian biosphere, their potential vulnerability and the key atmospheric and biospheric processes that influence the abundance of carbon dioxide.

The carbon cycle is central to the functioning of the earth system and to human well-being. It is inextricably coupled with climate, the water cycle, nutrient cycles and, through photosynthesis, provides the fundamental building blocks for life on the land and in the oceans. Humans depend upon the carbon cycle for food and fibre, and since the Industrial Revolution have depended on fossilised carbon compounds for much of our energy supplies.

The combustion of fossil fuels and land clearing, primarily for conversion of forests to agriculture, have led to a rapid increase of carbon dioxide in the atmosphere over the past two centuries. Since carbon dioxide is a greenhouse gas, its rapid atmospheric increase and the consequent changes in the energy balance at the Earth's surface and in the troposphere (lower atmosphere) have led to concerns about the future effects on the climate system.

Figure 18 illustrates the key interactions in the contemporary carbon cycle. The responses of the carbon cycle to human activities may seem very small compared to the large fluxes between the atmosphere and the ocean. However, it is important to note that during at least the last 420,000 years the net fluxes between land, ocean and atmosphere were close to zero. This was the case even when the Earth system was moving from a glacial to an interglacial state.

### Box 3: Carbon dioxide sources and sinks

A **source** of greenhouse gas is a process or activity through which the gas is released into the atmosphere. Both natural processes and human activities release greenhouse gases. Examples of carbon sources include the burning of fossil fuels and the decay of plants.

A **sink** for greenhouse gases is a process or a body in which carbon dioxide is taken up or 'sequestered' from the atmosphere. Examples of carbon sinks include plants as they grow and the oceans.

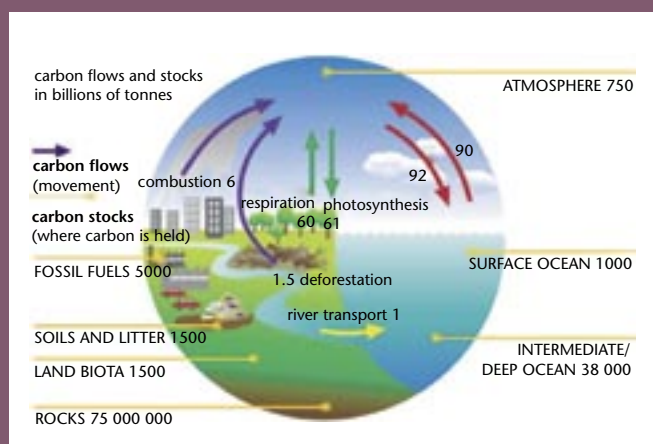


Figure 18: A representation of the global carbon cycle, including the human perturbations due to land use and fossil fuel combustion.



Figure 19: Burning vegetation releases carbon dioxide (Jason Beringer - School of Geography and Environmental Science, Monash University).

### Australia's terrestrial ecosystems pose scientific and policy challenges

To assess future impacts of climate change, evaluate effectiveness of carbon sequestration strategies, and improve confidence in projections of atmospheric concentrations of greenhouse gases, it is essential to consider the terrestrial contributions to the carbon cycle.

We have only a partial understanding of how the terrestrial carbon cycle operates, especially in terms of the processes that control the biological aspects of the cycle. What we do know is that Australia's terrestrial ecosystems are unique. As a result of climatic and geological factors, and the dominant role of fire, our ecosystems are markedly different from those in North America and Europe.

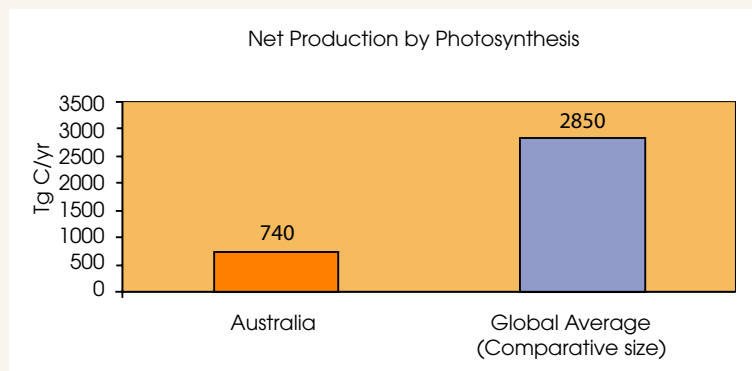


Figure 20: Difference between global and Australian net ecosystem productivity can be seen by comparing the annual average net production by photosynthesis for Australia with the global average for a continent of Australia's size (CSIRO).

### 1.4.1 Observing terrestrial carbon fluxes

Observations of carbon fluxes and pools are essential for understanding the behaviour of the carbon cycle at a fundamental level, and for testing research models of carbon cycle dynamics.

The ACCSP is currently supporting two flux towers – one at Tumbarumba in New South Wales and the other at Virginia Park in Queensland (Figures 21 and 22). This work focuses on:

- controls on the flux of carbon between the ecosystem and the atmosphere through observation of the year-to-year variation in fluxes. This is particularly important for Australian ecosystems given our highly variable climate and building understanding of the interaction between the carbon and the hydrological cycles;
- observation of abrupt or non-linear changes in carbon dynamics (e.g. effects of droughts and insect attacks on carbon fluxes at the Tumbarumba site see Figure 21);
- monitoring carbon fluxes in and out of the ecosystem for carbon budget purposes; and
- provision of high quality data for testing and improving models.



Figure 21: Flux tower at Tumbarumba, New South Wales (CSIRO).

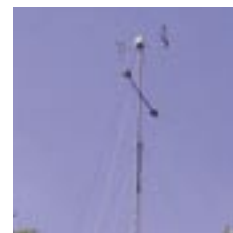


Figure 22: Flux tower at Virginia Park, Queensland (CSIRO).

### 1.4.2 A blueprint for Australian terrestrial carbon cycle research

In early 2005, the carbon cycle research community developed a blueprint for future terrestrial carbon cycle research in Australia.

The ACCSP will contribute to this research agenda which describes the following three research themes.

#### (a) Patterns of sources and sinks of carbon across Australia

Carbon is naturally transferred between atmospheric, oceanic and terrestrial pools via a rich array of chemical, physical, biological and - more recently - human processes. Determining the spatial and temporal pattern of these fluxes gives valuable insights into the processes that drive the carbon cycle, and contributes strongly to the knowledge base required to manage the carbon cycle responsibly.

The Australian terrestrial biosphere presents unique problems in determining and interpreting the patterns of carbon sources and sinks





Unlike many of the northern hemisphere terrestrial ecosystems, Australia's systems are both moisture and nutrient (especially phosphorus) limited, giving rise to different patterns of carbon source-sink strength and different interactions with climate variability.

From a policy perspective, Australia's large land mass, coupled with its relatively small population, implies that terrestrial sources and sinks play a disproportionately large role in the continental carbon balance compared to most other industrialised countries. Knowledge of the patterns of natural and modified carbon fluxes across the continent is essential background information to support Australia's national and international policy development.

### (b) Vulnerability of Australian terrestrial carbon sinks

Recent research suggests that the vulnerability of key aspects of the carbon-climate-human system have been underestimated.

Globally, there is growing recognition about the importance of terrestrial carbon sinks in the carbon cycle. Improved knowledge about the longevity and vulnerability of carbon sinks is required to understand the dynamics of the carbon cycle into the future.

After strong debate in the late 1990s about the notion of 'saturation' of the terrestrial carbon sink, **many scientists now believe that the global carbon sink of approximately 2-3 Gt yr<sup>-1</sup> will saturate, and possibly turn into a net source under some conditions.**

Key issues that need to be addressed in terms of the vulnerability of terrestrial carbon sinks in Australia include:

- Changes in temperature, precipitation/moisture availability and atmospheric CO<sub>2</sub> concentration – these can all strongly affect the fluxes of carbon between terrestrial ecosystems and the atmosphere.
- CO<sub>2</sub> fertilisation of plants - there is still debate about the magnitude of the CO<sub>2</sub> fertilisation effect in 'natural' ecosystems.

Effect of drought on forest productivity - Tumbarumba temperate native forest  
Mature mixed-aged stand

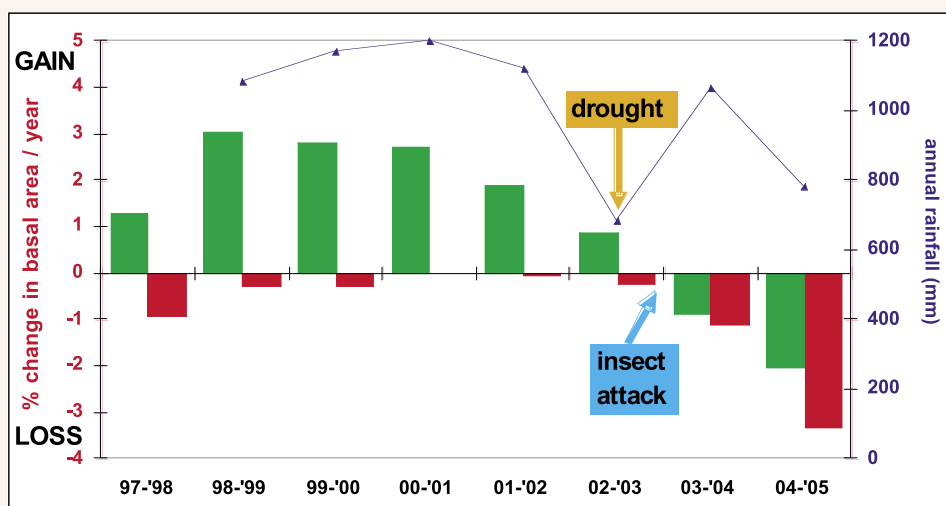


Figure 23: This graph shows the change in basal tree area, as an estimate of net carbon uptake, as a function of time. Green bars are live trees; red bars are dead trees; and the blue line is rainfall. The effects of drought and insect attack can be seen (CSIRO).

- Heterotrophic respiration (the mineralisation of soil carbon and subsequent emission of CO<sub>2</sub>) - how much of our terrestrial carbon pool is in the soil? This soil pool already experiences high temperatures; how sensitive is it to further increases in temperature?
- Temperature, moisture and productivity - the Tumbarumba flux tower site data show that the severe drought of 2002-03 reduced productivity from 10 tonnes of carbon per hectare in normal rainfall years to about 4 tonnes carbon per hectare. The drought also coincided with a severe insect attack, leading to defoliation and loss of productivity (Figure 23).
- Natural disturbances exacerbated by climate change - wind/storms, fire and host/parasite relationships affect the carbon dynamics of Australian ecosystems. A change in fire regime can mean a net shift in carbon stored in vegetation and soil to the atmosphere (or vice-versa, in the case of fire suppression). There is potential for pest and disease outbreaks in Australia, such as an enhancement of the incidence of Phytophthora, as climate changes.
- Land management practices inevitably affect the carbon cycle in a number of ways, both directly and indirectly.



Figure 24: Fire releases carbon stored in vegetation (Jason Beringer - School of Geography and Environmental Science, Monash University).

### (c) Development of a state-of-the-art carbon-climate modelling capacity

To remain competitive, the Australian global modelling capability will need to couple the carbon cycle with the physical climate

Global climate models generally are only now beginning to include representation of the terrestrial biosphere and its processes. Very few models currently dynamically include the terrestrial biosphere. This limits analysis of possible positive feedbacks between warming and the terrestrial carbon cycle.

Major steps to build this capacity in Australia over the next five years include:

- developing a complete, integrated land surface model within ACCESS that would include surface and sub-surface hydrology, carbon/nutrient cycles, water/energy exchange, vegetation dynamics, aerosols, land-use change, etc. ACCESS (Australian Community Climate and Earth System Simulator) is being developed by CSIRO and the Bureau of Meteorology with the support of the ACCSP (see section 2);
- undertaking a wide range of observations (e.g. atmospheric carbon dioxide concentrations, ground-based flux measurements, remotely sensed data) to enable testing and improvement of the model; and
- participating in the international model intercomparison of coupled climate-carbon cycle models to evaluate and verify Australia's model.

The Global Carbon Project (see Box 7, page 45) would provide the interface between an Australian national carbon cycle research programme and the international global change research programmes (see section 5).

## 1.5 Detection and attribution of climate change



(Jason Beringer)

What is the cause of the recent rainfall decline in southern Australia?

This research focuses on observed climate shifts in Australia and aims to distinguish between natural variability and climate change. This will provide a sound basis for prediction of future climate change and impacts.

**Detection** is the process of demonstrating that an observed climate change is larger (in a statistical sense) than could be expected from natural climate variability. **Attribution** is the process of determining the underlying causes of these climate changes. The detection, and attribution of the causes, of recent and current climate change provides a basis for the prediction of future climate change and impacts.

Researchers are seeking to disentangle long-term signals of climate change from a background of great climatic variability. This work is proceeding with high quality observations of climate, the oceans, land surfaces and the atmosphere. Analysis of historical climate data sets is a key step, as well as extended simulations by advanced climate models. At present, a variety of climate models are used for these studies within Australia. As the new modelling system ACCESS develops (see section 2), it is expected that it will be the main climate model used for Australian climate change detection and attribution studies.

### 1.5.1 Enhancing Australia's high quality climate data sets

High quality data sets for important climate variables are to be developed. The data sets cover daily temperature, evaporation, surface humidity, cloud and wind observations.

Work will include quality control and ensuring the data is easily accessed by the science community. These will be a valuable tool for detection and attribution studies.

### 1.5.2 Detection and attribution studies – apparent changes in Australia's climate

Studies will focus on those climate shifts most likely to have substantial socio-economic or ecological impacts, such as the recent decline in rainfall in south-eastern Australia.

The detection of recent and current climate change and attribution of the causes of these changes provides a basis for the prediction of future climate change impacts. The credibility of climate change impact predictions partly depends on our ability to explain Australia's recent past – i.e attribute the causes.

Studies will investigate:

- the strong increase in rainfall in the north-west of the country;
- the rainfall decline in south-east and coastal Queensland;
- trends in the frequency of some temperature extremes in some regions; and
- what change in the atmospheric circulation is the immediate cause of the decline in rainfall in south-west Western Australia?

Such questions can be answered by a combination of empirical, model and theoretical studies which increase our understanding of what is causing climate change.

There has been a reduction of 20 per cent in the peak strength of the southern hemisphere subtropical jet stream together with a shift southward. This has been shown to result in a reduction in the intensity of storm development of more than 30 per cent and the peak of the storm track over south-west Western Australia has shifted east (Figure 25). Such changes are consistent with the reduction of rainfall over southern Australia, especially over the south-west.

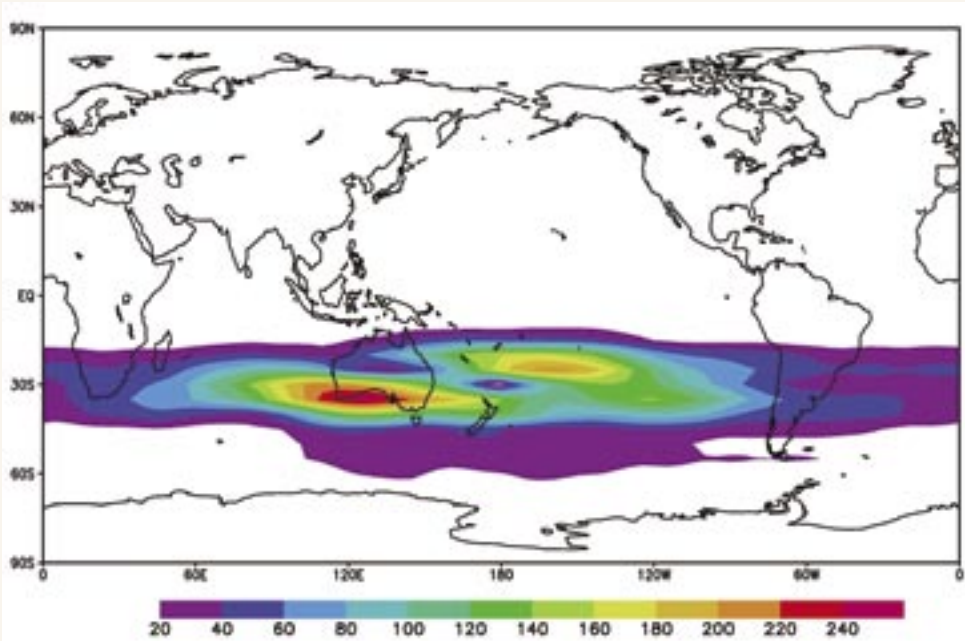


### 1.5.3 Understanding natural climate variability

Work will focus on understanding natural climate variations that occur on decadal timescales so that any climate change signal can be discriminated from naturally occurring variability.

One major influence on climate variability in Australia is the El Niño-Southern Oscillation (ENSO). Modelling the effects of sources of variability such as the ENSO is essential for attribution. Extended simulations by models capable of reproducing the behaviour of ENSO and other factors affecting Australian climate, with different external and natural forcings (e.g. stratospheric ozone, greenhouse gases, aerosols and volcanic activity) are required.

1949-68



1975-94

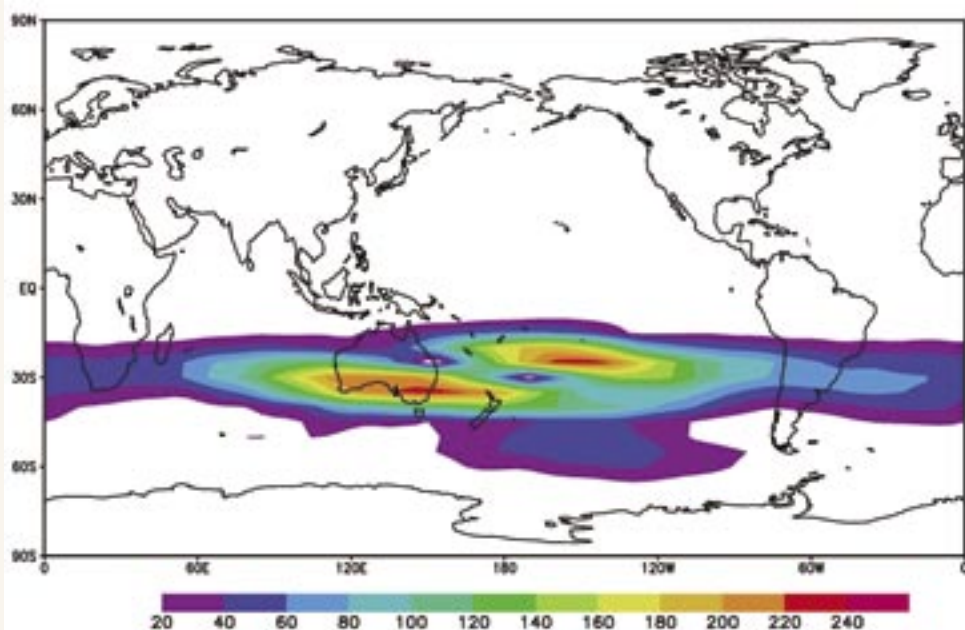


Figure 25: Observed changes to the mean position of the main storm tracks, which affect southern Australia. The relative impact of the storms at the 300hPa pressure level as they develop eastward is shown. Red indicates regions most affected by storms. During 1949-68, south-west WA was the preferred region for storm development. More recently, storms are less likely to form in the west and the favoured region of development has shifted east (shown in red). The rainfall decline in south-west WA is linked to these changes in large-scale circulation (BMRC and CSIRO).

#### Box 4: Climate anomalies in Australia – what are the causes?

A number of apparent shifts in regional climate have recently been observed in Australia, and there is a need for studies to determine whether these are genuine changes in regional climate and, if so, what has caused them.

- Australia has warmed 0.9°C from 1910-2004, mostly since 1950, with minimum temperatures rising at twice the rate of maximum temperatures. Regional climate model simulations indicate that the warming is likely to have been caused by both natural variability and the enhanced greenhouse effect.
- Warming in south-east Australia has been linked to the observed 40 per cent decline in October snow depth in the past 40 years in the Australian Alps.
- 20th century cooling of daytime temperatures in New South Wales occurred suddenly mid last century – the cooling was associated with a steep increase in rainfall during the 1940s. Since the middle of the century, maximum temperatures have risen independent of rainfall changes.
- Studies of the decline in early winter rainfall since the early 1970s in south-west Western Australia concluded that it was likely due to a southward shift in weather systems in the southern hemisphere caused by the enhanced greenhouse effect, ozone depletion and natural variability.
- The decline in rainfall in April-July in south-east Australia also started in the early 1970s but became more obvious since 1996. This seems related to the southward shift in weather systems.

- Decline in rainfall in second half of 20th century along eastern (especially coastal) New South Wales and Queensland. This is related to a higher frequency of El Niños since the mid 1970s, but the cause is uncertain.
- Increased rainfall in north-west Australia. This may be due to both natural variability and the enhanced greenhouse effect.
- Decrease (3%) in pan evaporation across Australia from the 1970s to the 1990s. Work suggests that some of the decrease is due to a decrease of wind speeds.



## 1.6 Historical records - palaeo-science reveals the past



### Clues to understanding our future climate are hidden in the past

Historical records – palaeo-climatic data from past centuries and millennia – have been extracted as ice cores from glaciers and ice caps, from tree rings, the skeletons of tropical coral reefs, and from laminated sediments from lakes and the ocean. This work has helped place the current observed changes in the atmosphere in a longer historical perspective. Palaeo-records reveal that change has not always been gradual, and that there have been some abrupt climate events in the past (see Box 5).

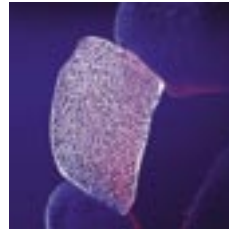
The extended history provides a perspective of how much current human influence has perturbed atmospheric concentrations from their natural range over past centuries and millennia. For example, chemical analysis of water and trapped air bubbles in ice cores from Antarctica has revealed much about the world's climate over the past 400,000

years. Future ice core analysis from Dome C in Antarctica – by France and Italy – is expected to reveal a climate history dating back more than 900,000 years. These records provide a database against which the theoretical models that represent the global budgets of gases in the climate system can be tested for their veracity.

Similarly, cores from marine and terrestrial sites have provided records of past global and regional climates over a range of timescales (millennial to sub-decadal) and the impacts of climate change on both the marine and terrestrial environment. The records show that not all changes have been gradual. Terrestrial records and near shore marine records (such as those derived from corals) are particularly important in that they provide evidence of the direct impacts of climate change on environments in which humans live. This includes the effects of climate change on flora and fauna, water resources and landscape processes such as erosion.



Figure 26: Slice of an Antarctic ice core showing the bubbles of trapped air (CSIRO).



The ACCSP has supported some aspects of the ice core work, leveraging the work of the Australian Antarctic Division and CSIRO and the Antarctic Climate and Ecosystems CRC. The work has also involved other national and international collaborators including ANSTO, the Australian Bureau of Meteorology, New Zealand National Institute for Water and Atmosphere and the University of Colorado.

In July 2005 a two-day workshop for palaeoclimate scientists and climate modellers was held at the Australian Academy of Sciences in Canberra to discuss how reconstructions of past climate change might be better applied to modelling future potential climate change.

The workshop revealed a range of data gaps and research that should be addressed to improve the resolution and coverage of palaeo-data and raise the national and international profile of Australian palaeo-science.

**Work has commenced to construct high-resolution multi-proxy records from existing data for temperature and precipitation across the Australian region over the last 500-2000 years.**

This will be the first such climate reconstruction for the southern hemisphere. Northern hemisphere climate reconstructions have dominated scientific discussion to date. Australia's work will be an important contribution to the global picture of past climates.

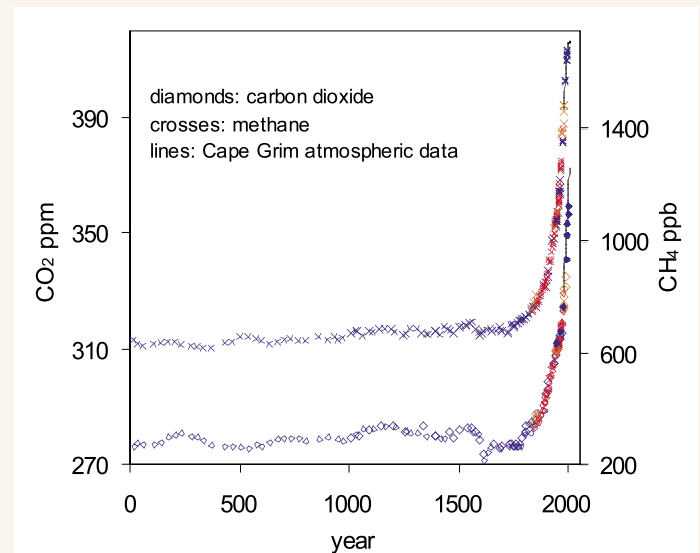


Figure 27: Record of historical changes in atmospheric concentration of methane and carbon dioxide revealed in air from ice measurements (CSIRO).



Figure 28: Drilling coral cores (Australian Institute of Marine Science/ Matson).



## Box 5: Abrupt climate change

Numerous palaeo-climate records show that large, abrupt climate changes have occurred repeatedly in the past, affecting our climate on hemispheric and global scales. This is consistent with the results from modelling that indicate forcing of climate increases the possibility of crossing thresholds that trigger abrupt change.

Before the 1990s, the dominant view of past climate change emphasised the slow, gradual swings of the ice ages tied to features of the Earth's orbit over tens of millennia or the 100-million-year changes occurring with continental drift. But unequivocal geological evidence pieced together over the last few decades shows that climate can change abruptly, and this has forced a re-examination of climate instability and feedback processes.

Greenhouse warming and other human alterations of the earth system may

increase the possibility of large, abrupt, and unwelcome regional or global climatic events. The abrupt changes of the past are not fully explained yet, and climate models typically underestimate the size, speed, and extent of those changes. Hence, future abrupt changes and possible timeframes cannot be predicted with confidence, and climate surprises are to be expected.

The most significant rapid climate change event that occurred during the last deglaciation of the North Atlantic region was the Younger Dryas, 12,900 – 11,500 years Before Present. The prevailing theory holds that the Younger Dryas was caused by a significant reduction or shutdown of the North Atlantic thermohaline circulation in response to a sudden influx of fresh water from deglaciation in the north American continent. The Younger Dryas saw a rapid return to glacial conditions in the higher latitudes of the northern hemisphere in sharp contrast to the warming of the preceding interstadial deglaciation.

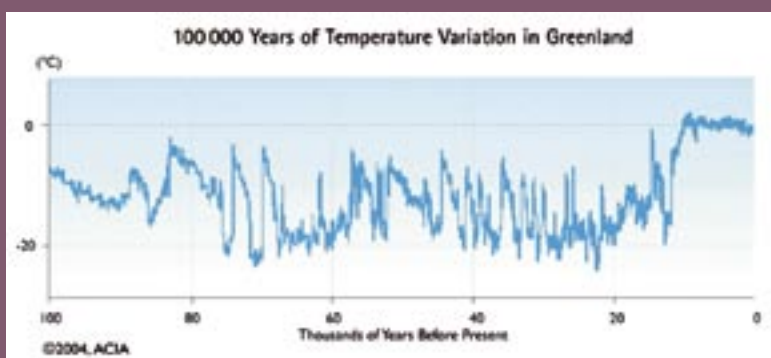
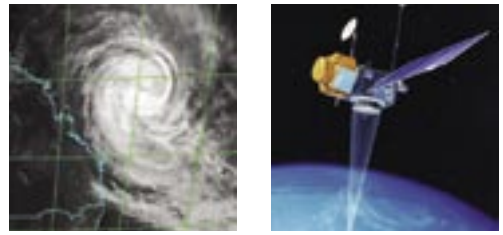


Figure 29: This record of temperature change (departures from present conditions) has been reconstructed from a Greenland ice core. The record demonstrates the high variability of the climate over the past 100 000 years. It also suggests that the climate of the past 10 000 years or so, which was the time during which human civilisation developed, has been unusually stable. There is concern that the rapid warming caused by the increasing concentrations of greenhouse gases due to human activities could destabilise this state.

## 2. AN AUSTRALIAN CLIMATE MODELLING SYSTEM



Global climate models support policy formulation by integrating our current knowledge base on the climate system and by providing scenarios of plausible future trajectories of climate given various forcings. It is in Australia's interests to develop and maintain a state-of-the-art global climate modelling capability, rather than relying on climate models imported from the northern hemisphere.

Australian climate modelling is about to enter a new era with the development of the Australian Community Climate Earth System Simulator (ACCESS)

The development of ACCESS was initiated through the ACCSP and is being led by CSIRO and the Australian Bureau of Meteorology, and with strong links to university research groups. This collaboration brings together scarce resources and increases critical mass in an area of climate change science that is fundamental to Australia's national capacity as well as our international standing.

ACCESS will feature a new generation global and regional climate modelling capability, include a

fully coupled carbon cycle model, and eventually provide the opportunity for incorporation of socio-economic processes. A long-term goal is the development of models that describe the interactions between climate, terrestrial and marine biogeochemical cycles, ecosystems, and human activities such as energy, land use and urbanisation regimes. These models would have the capacity to assess longer-term (multi-decadal) implications of economic and social development on the global environment, and climate-greenhouse interactions in particular. These models would have the potential to inform policy assessments for Australia and our region.

The scope of ACCESS will include the modules shown in Figure 30 and a comprehensive data assimilation component. In addition, ACCESS will need to address the requirements of related projects such as regional downscaling, impacts and assessments. It also aims to develop synergies with research in numerical weather prediction and seasonal forecasting.

ACCESS modelling outcomes will provide the best possible science for use in analysis of climate impacts and adaptation, and enable a world-class Australian contribution to the 5th Assessment Report of the Intergovernmental Panel on Climate Change.

**Development of the ACCESS model system is expected to take several years.**

Initial stages of ACCESS are expected to include:

- an Earth System Model, including a capacity for regional downscaling;
- comprehensive data assimilation for the atmosphere, ocean, and land-surface parameterisation; and
- model evaluation to ensure good performance.

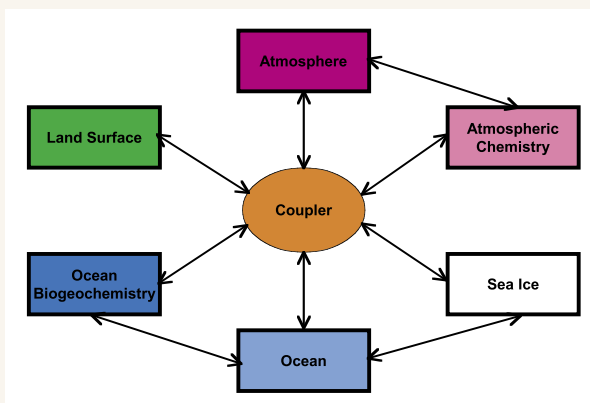


Figure 30: A schematic of the configuration of an Australian Community Climate Earth System Simulator (Bureau of Meteorology).



A plan for the system development is expected to be publicly available in 2006.

In the meantime, existing models will be used to satisfy requirements of climate impacts research. This work is underway with the first climate change simulations performed using the recently developed CSIRO Mk3.5 model.

CSIRO has developed a flexible-grid regional climate model Cubic Conformal Atmospheric Model (C-CAM) to 'downscale' the broad patterns of change simulated by the global models to the regional scale (see Figure 31). The ability of C-CAM to simulate the observed features of climate variability over the Australian region is being evaluated to provide confidence in using the model to ascertain the potential for changes in climate variability resulting from global warming.



Figure 31: C-CAM flexible grid regional climate model.

CSIRO has developed the Cubic-Conformal Atmospheric Model, known as C-CAM. C-CAM generates regional simulations in a unique way. It uses a 'stretched grid' pattern, in which the greatest climatic detail is determined for the area of finest resolution. Typical model resolution is 60 kilometres, with some highly detailed simulations using 14 kilometre grid spacing (CSIRO).





### 3. CLIMATE CHANGE, CLIMATE VARIABILITY AND EXTREME EVENTS



Many of the impacts of climate change will be felt through changes in the frequency and intensity of extreme climate events

Understanding Australian climate variability and how climate change will impact on this variability and the frequency or intensity of extreme events is a vital area of research for Australia. Australia experiences one of the most variable climates on Earth. Our ability to manage the threats and opportunities associated with climate variability is limited by lack of understanding of key processes involved. The research being undertaken is essential to underpin the National Climate Change and Adaptation Programme.

Many of the impacts of climate change will be felt through changes in the intensity and/or frequency of extreme climate events, such as heat waves, heavy rainfall, wind gusts, cyclones, storm tides, fire risk, drought, hail and composite events such as severe winds combined with flooding.

Extreme weather events have caused major damage and loss of life in Australia in the past century (e.g. Federation drought of 1895-1901) and continue to do so (e.g. Ash Wednesday fire February 1983, Sydney-Hobart yacht race storm of December 1998, Sydney hailstorms of April 1999 and Canberra bushfires of 2003).

These extremes are expected to change in intensity, location-specific frequency and sequence as a result of climate change. There is good evidence that the climatology of severe events in Australia is changing in an observable way.

#### 3.1 Modelling extreme climate events in Australia

Extreme events currently being investigated and modelled are extreme rainfall and wind events, tropical cyclones, hail and severe storms, storm surges and sea level rise, drought and fire risk in south-eastern Australia. Outputs will allow researchers to quantify changes in the intensity and frequency of these events.

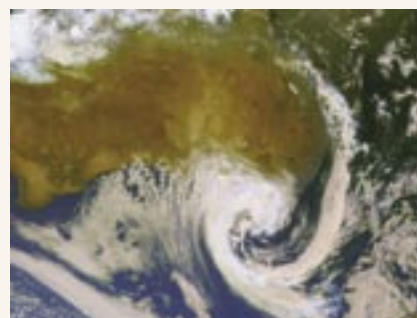


Figure 32: Extreme weather system over Melbourne February 2005 bringing heavy rainfall.

#### 3.2 Understanding changes in natural modes of variability

Why was the 2002 El Niño event less intense than the event of 1997 but the drought associated with it was more severe?

This research will investigate the effect of climate change on natural modes of variability such as the El Niño-Southern Oscillation (ENSO), Indian Ocean Dipole (IOD), the Interdecadal Pacific Oscillation (IPO) and the Antarctic Oscillation.

Climate change may manifest itself as a change in the natural modes of variability of the climate system. Changes in the mean state of the ocean or atmosphere (e.g. a warming of the tropical oceans, or a shift in atmospheric pressure) may alter the frequency or intensity of ENSO or other modes of variability. It has been recognised for some time that a small shift in the long-term

## Stormtides along Eastern Victoria

Sea level rise will have a much larger impact in this region than wind speed changes

### 1 in 100 year sea levels

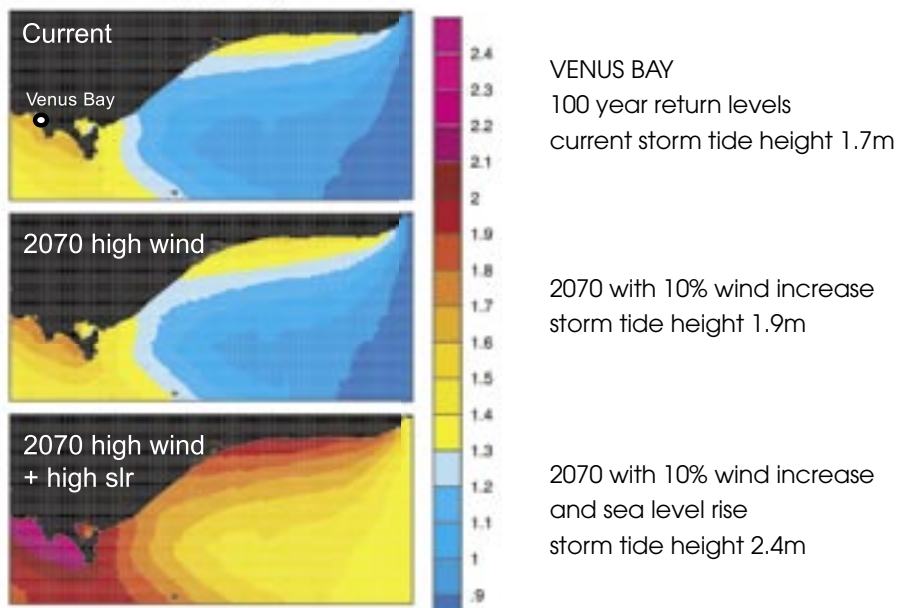


Figure 33: Venus Bay, Victoria. The spatial pattern of the 1 in 100 year storm tide heights (m) under (a) current climate conditions (b) 2070 climate conditions with a high wind speed change scenario applied and (c) 2070 with high wind speed and sea level increases applied (CSIRO).

mean, or variance, of a variable may produce substantial changes in the climatology of extreme instances of that variable. Some aspects of changes in extreme climate events can be estimated from projected mean changes, but many aspects of extreme events need to be explicitly investigated and modelled.

There is a growing body of evidence that suggests that human activities may be capable of changing the time-averaged states of the natural modes of variability of the climate system, most notably, the ENSO and southern hemisphere annular modes. An understanding of these modes and how they react to anthropogenic forcing is essential for detection and attribution of climate change and for interpreting the role of feedbacks. The natural variability of these modes on a year-to-year time

scale provides a baseline for testing the outputs of climate models.

Significant advances have been made in understanding and predicting ENSO, but we are still unable to forecast the duration or intensity of drought associated with El Niño events, or to explain why the impact of El Niño on Australian climate varies from event to event and from region to region. For example, we need to understand why the 2002 El Niño event was less intense than the event of 1997, and yet the drought associated with it was more severe. A first step in the research is to eliminate the bias in climate model simulations of the tropical Pacific 'cold tongue' (see Box 6).

Other modes of variability affecting climate being investigated are the Indian Ocean Dipole (IOD),



the Interdecadal Pacific Oscillation (IPO) and the Antarctic Oscillation, which have all been linked to climate variability in regional Australia. These processes are poorly understood and poorly simulated in models.

The IOD is a major part of the Earth's interdecadal climate variability. It is a see-saw pattern of sea surface temperature anomalies between the central equatorial Indian Ocean and Indonesian waters. The IOD index correlates with Australian rainfall, especially over the western half of the continent. Researchers will investigate the dynamics of the IOD and the relationship between the Indian Ocean warming trend and the climate shift that has occurred in Western Australia over the past 30 years.

Using climate models, programme researchers will investigate the character, dynamics and predictability of the IPO. The IPO, first named in 1999, changed phase near the time of the Pacific 'climatic shift' around 1976 and apparently influenced global temperatures. The IPO sea surface temperature pattern, which differs in several ways from the ENSO pattern, has just as much variability in the South as the North Pacific. Although it remains unclear to what extent the phenomenon is physically separate from ENSO fluctuations. Recent modelling by the Hadley Centre in the UK confirms that an sea surface temperature pattern like that of the IPO modulates ENSO influences on rainfall over Australia in a broadly similar way. The implication is that the state of the IPO may be important to long-range forecasts of ENSO effects on Australian rainfall a season or a few seasons ahead.

The Antarctic Oscillation, also referred to as the Southern Annular Mode (SAM), is a mode of atmospheric variability in the southern hemisphere in high latitudes. Some studies have reported a trend in the SAM towards its positive phase - when pressures over Antarctica are relatively low compared with mid-latitudes. This entails

a strengthening of the circumpolar vortex and intensification of the westerlies that encircle Antarctica. These studies suggest that the strengthening of the circumpolar vortex is 'pulling' the westerlies that bring rain to southern Australia further south and is contributing to the decline in rainfall, particularly in south-west Western Australia, observed over the past 30 years. Programme research will investigate the effects of climate change on the SAM.



## Box 6: The ENSO 'cold tongue' – a challenge for modelling

The 'cold tongue' is a band of cold surface waters about 1000 km wide, extending westward from the South American coast along the equator into the central Pacific (see Figure 34 below). It is usually present during La Niña conditions, sometimes disappearing completely when El Niño prevails.

Easterly winds blowing along the equator bring cold sub-surface water to the surface, generating the cold tongue. This region is particularly sensitive, and intimately linked to the strength of El Niño. Hence, it is important to accurately include the region of cool temperature in models that simulate El Niño and La Niña events.

Current climate models tend to simulate a cold tongue that projects too far to the west. So the timing and atmospheric response associated with simulated El Niños are less accurate than they should be - e.g. simulated rainfall variations are too far to the west. Researchers in the Programme are improving the representation of physics associated with interactions between the ocean and the atmosphere in the tropical Pacific.

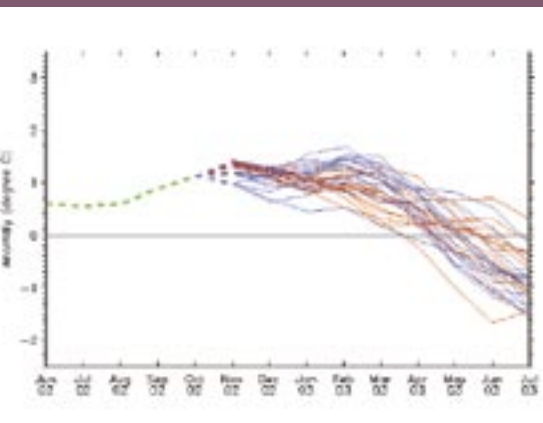
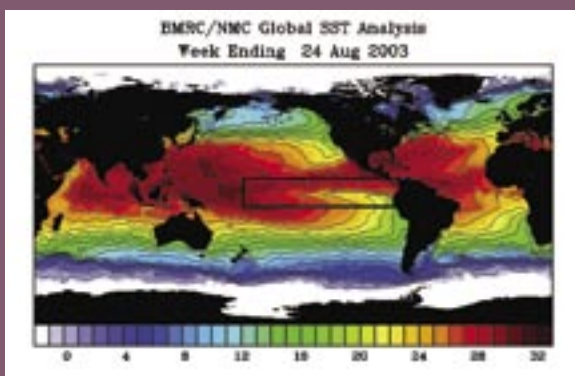


Figure 35: This graph shows the variation with time of the prediction of sea surface temperature in the region of the eastern Pacific. The green line represents observed ocean temperatures. Each line represents a model run from each day in November 2002. The increased ensemble spread indicates the increasing uncertainty in the outcome as we go further into the future (Bureau of Meteorology and CSIRO).

Figure 34: The ENSO 'cold tongue' (inside the black line) extending along the equator from the eastern Pacific. Colour bars represent degrees Celsius.



## 4. REGIONAL CLIMATE CHANGE PROJECTIONS

**This work will develop the capacity to prepare projected ranges of change with probabilities.**

The policy relevance of this work for governments, industries and non-government organisations is high. Regional climate projections provide essential input for assessment of potential impacts and adaptation, particularly for determining changes to extreme events.

There is much uncertainty in projections due to different climate forcing scenarios, future greenhouse gas scenarios, aerosols, ozone depletion, different climate sensitivities, different patterns of climate change between models, and chaos.

New approaches to climate change projections are being employed, including quantifying the associated uncertainties and risks.

This work will enhance climate projection-building methods and develop the capacity to prepare ranges of change for given confidence intervals (probabilistic projections). This will then allow researchers to prepare new projections of regional climate change for a broad range of variables. Work will also begin in 2006-07, and extend into the following year, on developing a method of combining climate change projections with decadal climate variability.

The first step in providing useful regional projections is to make the global model as good as possible at the regional scale. Then a downscaling model is required to take local effects into account, such as the location of a mountain range. Development of downscaling techniques is improving projections of changes in average climate at the local-to-catchment scale.

The Programme will further develop the OzClim climate projection research tool and impact assessment interface over the next three years. The database could be enhanced with the addition of more reliable climate models, more climate variables, and an improved ability to connect with impact assessment models. This will significantly enhance a key delivery mechanism for regional projections.

OzClim is a climate scenario generator for Australia that simplifies the process of calculating future climate change for application to impact models. It is a PC-based software tool that features a graphical user interface and point and click technology. This system allows comparison of output from a range of global climate models and construction of future climate change scenarios for risk assessment. The ability to 'plug in' impact models into OzClim and run a given model multiple times with different scenarios are further advantages of the software. Outputs from the extreme climate events work will be included in OzClim.





## MODEL HIERARCHY

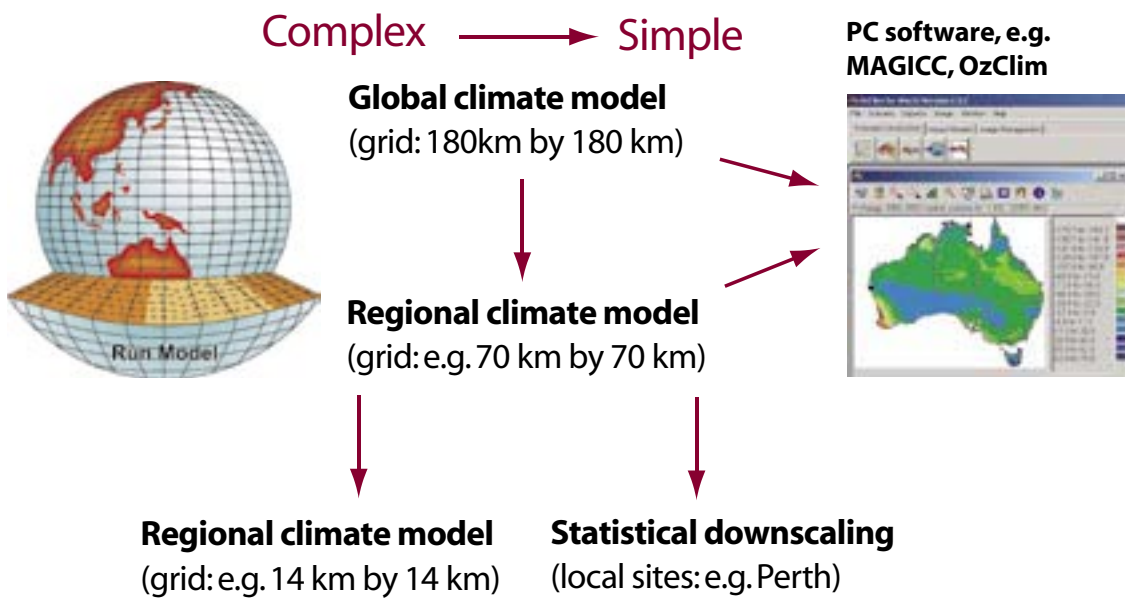
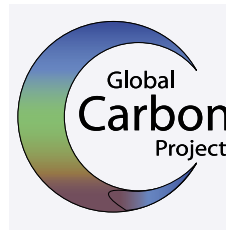


Figure 36: Downscaling global models for regional modelling - OzClim (CSIRO).



Figures 37 and 38: Managers of natural and managed systems will benefit from more certainty in climate projections.

## 5. INTERNATIONAL COLLABORATION



### Enhancing Australian influence on global research and our climate change research capability in the southern hemisphere

The ACCSP has contributed significantly to the international recognition of Australia's climate change science, and the importance of the southern hemisphere in global climate analysis. The credibility achieved by our scientists has enabled Australia to influence the priorities for greenhouse research at a global scale and obtain knowledge and resources from other countries to our benefit.

The 2003 evaluation of the Programme noted that "there has been extraordinary leverage of international scientific resources into our areas of interest for a modest investment; the benefit/cost ratio is very high".

Australia is a strong contributor to United Nations Framework Convention on Climate Change scientific processes, especially related to the IPCC. Work is underway for the Fourth Assessment Report, to be published in 2007.

The ACCSP and its participating scientists contribute to important bilateral and multilateral relationships between Australia and other countries. For example, elements of oceanic research contribute directly to the Australia-United States Climate Action Partnership. This partnership is scientifically and strategically important to Australia.

Through the support of the ACCSP, Australia participates in international climate change research programmes such as the World Climate Research Programme (WCRP) and the International Geosphere-Biosphere Programme (IGBP) which are sponsored by the International Council for Science.

The objectives of the WCRP are to develop the fundamental scientific understanding of the physical climate system and climate processes

needed to determine to what extent climate can be predicted and the extent of human influence on climate. The programme encompasses studies of the global atmosphere, oceans, sea and land ice, and the land surface that together constitute the Earth's physical climate system. The IGBP focus is global biogeochemistry – studying the interactions between biological, chemical and physical processes and human systems.

The ACCSP supports the Global Carbon Project (GCP) by providing funding to its Canberra office. The GCP is an international programme associated with the WCRP, IGBP and a third called the International Human Dimensions Programme on Global Environmental Change. Australian scientists play a key role in GCP through the establishment of the Canberra office.

Major goals of the GCP are: to develop a research framework for integrating the biogeochemical, biophysical and human components of the global carbon cycle; and to provide a global platform for coordinating international and national carbon programmes.

The GCP provides an interface between Australian carbon cycle research and the international research programmes that are coordinated by the GCP. The GCP office will lead the organisation of several international activities in Australia that will contribute to the development of a stronger national capability to detect and attribute critical carbon sources and sinks on the Australian continent, and to quantify their vulnerability under climate change (see section 1.4.2 – Blueprint for Australian Terrestrial Carbon Cycle Research).

An international activity will be initiated this year in collaboration with the Australian Research Council (ARC) funded Earth System Sciences Network to analyse the observational and modelling requirements for accounting of carbon sources and sinks from fires, and their future vulnerability under land-use change and climate change.

The GCP and the ARC are expecting to run a first meeting in Australia within the next 12 months.

A workshop is planned to take place in Australia, led by the GCP and co-sponsored by European Space Agency, CSIRO, and the ARC-Earth System Sciences. National and international delegates will:

- review the current status of research in model-data synthesis for constraining the coupled terrestrial carbon and water cycles, including models, observations and synthesis techniques;
- develop opportunities and mechanisms for international collaboration among modellers, observers and synthesisers, to the benefit of both national and international projects; and

- contribute to the long-term goal of developing, parameterising and applying coupled terrestrial biogeochemistry modules in earth system models.

In conjunction with the workshop on coupled terrestrial carbon and water cycles, a second workshop - Optimisation InterComparison (OptIC) - will be held for comparing and evaluating parameter estimation and data assimilation approaches for terrestrial biogeochemical cycles. This is an activity led by the GCP, and co-sponsored by the European Space Agency.

### Box 7: Global Carbon Project

The goal of the GCP is to develop comprehensive, policy-relevant understanding of the global carbon cycle, encompassing its natural and human dimensions and its interactions. The GCP will focus on three themes:

- **Patterns and Variability:** What are the current geographical and temporal distributions of the major pools and fluxes in the global carbon cycle?
- **Processes and Interactions:** What are the control and feedback mechanisms – both anthropogenic and non-anthropogenic – that determine the dynamics of the carbon cycle?
- **Carbon Management:** What are the likely dynamics of the carbon-climate-human system into the future, and what points of intervention and windows of opportunity exist for human societies to manage this system?

The GCP will implement this agenda by:

- Developing a research framework for integrating the biogeochemical, biophysical and human components of the global carbon cycle.
- Providing a global platform for fostering coordination among international and national carbon programmes to improve the design of observations and research networks, data standards, information transfer, and timing of campaigns and process-based experiments, and the development of model-data fusion techniques.
- Fostering research on the carbon cycle in regions that are poorly understood but have the potential to play important roles in the global carbon cycle.
- Synthesising and communicating new understanding of the carbon-climate-human system to the broad research and policy communities.



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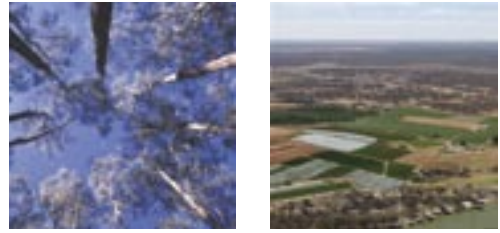


[Roger Good]



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