Australian ClimateChange ScienceProgram

Annual Report 2011—2012

The Australian Climate Change Science Program – An Australian Government initiative.

Australian Government
Department of Climate Change and Energy Efficiency

CSIRO

Australian Government
Bureau of Meteorology

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Produced by Kathy Pullman
Layout by Carl Davies CSIRO

Reviewed by staff from CSIRO, the Bureau of Meteorology, and the Department of Climate Change and Energy Efficiency. The researchers mentioned throughout the report and others also contributed their expertise.

The Australian Climate Change Science Program – An Australian Government initiative.

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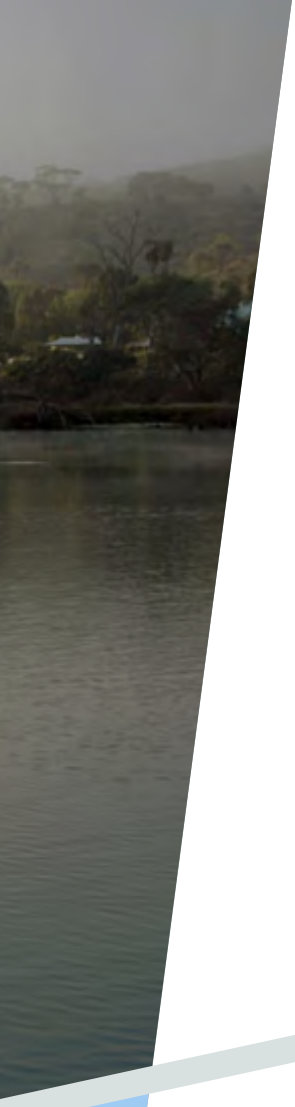
MARINE RESEARCH
SOUTHERN SURVEYOR
SONAR
12.0 FT UNDERSHIPS KEEL



Foreword

The Australian Climate Change Science Program (ACCSP) has a major role in informing Australia's key decision makers and improving our understanding of the causes, nature, timing and consequences of climate change.

In 2011-12, more than 100 climate scientists throughout Australia worked on 27 projects across seven program areas that addressed national climate change science priorities. As well as carrying out climate change research, the scientists presented their findings at workshops, conferences and other events throughout Australia and overseas. They published their findings in 110 peer-reviewed papers in Australian and international publications (see Appendix 5).

ACCSP science continued to address the questions and issues around the impacts of rising carbon dioxide emissions. Global carbon dioxide emissions from fossil-fuel burning grew 5.9 per cent in 2010. This is the highest level of total emissions recorded. It is also the highest annual growth rate since 2003. The 2010 growth rebounds from the 1.4 per cent Global Financial Crisis (GFC)-induced drop in emissions recorded in 2009. This puts global carbon dioxide emissions back on the same high-growth path that they were on before the GFC.

The science undertaken by the ACCSP in the reporting year improved our understanding of what changes we are seeing now, what changes we are likely to see in the future, and the consequences of a future warmer climate due to greenhouse gas emissions. ACCSP science addressed the following themes: greenhouse gases, atmosphere, coasts and oceans, water, an Australian climate modelling system, extremes, and communication. The science in these areas provided new or supported existing scientific evidence for human-induced climate change.

In addition to this work, many ACCSP scientists published papers on the outcomes of their work over the past five years for inclusion into the Fifth Assessment Report for the United Nations Intergovernmental Panel on Climate Change (IPCC). The IPCC – which involves thousands of climate change experts around the world – was established by the World Meteorological Organization and the United Nations Environment Programme to assess scientific, technical and socio-economic information concerning climate change, and its potential effects and options for adaptation and mitigation. The Fifth Assessment Report will be finalised throughout 2013-14.

To address key policy questions, the Australian Government, in consultation with the scientific community, developed and released *A Plan for Implementing Climate Change Science in Australia.* This plan will improve integration and collaboration, and provide a blueprint to support the delivery of world-class science in this country. It will ensure that core climate system science continues to be carried out to answer key policy questions and to underpin the country's decisions on adaptation, mitigation, and shaping a global solution.

Australia's climate change science would not have been possible without the passion of our scientists and staff who are committed to improving our understanding of climate change and addressing the challenges ahead. We would also like to acknowledge the Department of Climate Change and Energy Efficiency, which has supported CSIRO and the Bureau of Meteorology as the providers of the climate science undertaken by the ACCSP. This collaboration has been critical in helping Australia's decision makers understand the impacts of climate change and to develop ways for our country to adapt to and manage its carbon emissions.

Mr Paul Holper

Manager,
Australian Climate Change
Science Program

Dr Robert Colman

Climate Variability and Change Program,
Centre for Australian Weather and
Climate Research,
Bureau of Meteorology

Vision

To be a world-class provider of science-based knowledge on climate change in the southern hemisphere.

About

The Australian Climate Change Science Program (ACCSP) is a major Australian Government climate change science program.

The world-class science carried out by the ACCSP informs Australia's key decision makers and improves our understanding of the causes, nature, timing and consequences of climate change.

The ACCSP plays a significant role in contributing to, and informing, public policy and debate on climate change.

Climate change science

Climate change science provides the information needed to understand and plan for climate change impacts, thereby increasing community resilience and reducing the cost to society. It is needed to understand the size of the mitigation challenge and to set appropriate reduction targets for emissions of greenhouse gases. It also strengthens our international negotiating position and helps shape a global solution.

Science undertaken by the ACCSP focuses on the southern hemisphere because most other climate change science is generated in the northern hemisphere and does not provide all the information needed for Australian decision making.

In 2011-12, the ACCSP comprised 27 projects within the following research program areas:

1. Global and regional carbon budgets
2. Land and air (observations and processes)
3. Coasts and oceans (observations, processes, projections)
4. Modes of climate variability and change
5. Earth systems modelling and data integration
6. Australia's future climate
7. Communication and coordination

See Appendix 1 for a list of the ACCSP projects carried out in 2011-12.

Working together

Since 1989, the Australian Government has supported climate change research undertaken by CSIRO, the Bureau of Meteorology and other agencies.

A major component of this is the ACCSP, which is a partnership between the Department of Climate Change and Energy Efficiency (DCCEE), CSIRO and the Bureau of Meteorology (BoM).

With co-investment by CSIRO and BoM, the ACCSP invested approximately $15m in 2011-12 in climate science to meet the shared goals and priorities of CSIRO, BoM, and DCCEE. A partner program is investigating climatic extremes. These goals and priorities were also expanded by the joint research program between CSIRO and BoM through the Centre for Australian Weather and Climate Research (CAWCR).

National climate science priorities

All ACCSP projects are aligned with the Australian Government's 2009 *National Framework for Climate Change Science* (the Framework) which sets out the national climate science priorities needed to address the following climate change challenges facing us over the coming decades:

- Greenhouse gases
- Water
- Coasts and oceans
- Extreme events
- Atmosphere.

This year, the Australian Government developed and released *A Plan for Implementing Climate Change Science in Australia* (the Plan). The Plan is the next step in implementing the Framework and it articulates the science priorities to guide investment decisions and ensure that the maximum national benefit is delivered to the Australian community. It describes key climate policy questions and includes specific science deliverables that will address those questions and help Australia to:

- Mitigate its impact on the climate
- Adapt to the effects of climate change
- Shape a global solution to climate change.

Climate science delivered by the ACCSP is designed to address the key policy questions and contribute to the achievement of the deliverables identified in the Framework.

More information about Australia's climate change science priorities can be found at: http://www.climatechange.gov.au/climate-change/national-framework-science/plan.aspx

International collaboration

The ACCSP ensures that Australian climate change science continues to be recognised internationally by:

- Investing in high-quality climate change research that contributes to peer-reviewed publications in national and international journals;
- Citation of our publications in the Assessment Reports produced by the IPCC;
- Funding scientists to contribute to important bilateral and multilateral relationships between Australia and other countries;
- Supporting Australia's participation in international research, and our influence in international research priorities through such bodies as the World Climate Research Programme and the International Geosphere-Biosphere Programme; and
- Supporting the Global Carbon Project, which aims to develop a comprehensive policy-relevant understanding of the global carbon cycle.

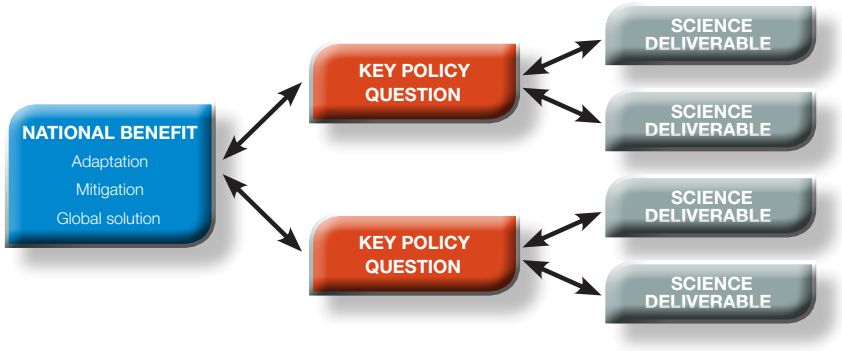


Figure 1. The Plan describes key climate policy questions and includes specific science deliverables that will address those questions and help Australia mitigate its impact on the climate, adapt to the effects of climate change, and shape a global solution to climate change.

Activities at a glance

Table 1. ACCSP activities in 2011-12

What	How many	Page
Research program areas	7	2
Projects	27	Appendix 1, 41
Other partners – universities	18	Appendix 2, 42
Other partners – national	10	Appendix 2, 42
Other partners – international	43	Appendix 2, 42
Media releases	17	Appendix 3, 43
Websites	8	Appendix 4, 45
Peer-reviewed publications	110 published, 13 in press, and 14 submitted	Appendix 5, 46
Other publications	29	Appendix 6, 52

What was delivered, at a glance

Table 2. In 2011-12, the ACCSP delivered outcomes that addressed the key climate research themes:

Key climate research theme	Research program area	Our targets	Key science outcomes	Pages
Greenhouse gases	**Global and regional carbon budgets** *Quantifying changes to the carbon cycle in the Australian region and globally*	• The carbon balance of the Australian continent for 1990-2009 (including its component sink and source fluxes) measurements and model outputs from Australian and global analyses • An understanding of global and regional patterns of carbon sources and sinks, what drives them, and ways to manage carbon to stabilise atmospheric carbon dioxide and other greenhouse gases • An estimate of the sensitivity of greenhouse gas changes to decadal and centennial changes in climate using models to understand ice core and air in compacted snow measurements of carbon dioxide, methane, nitrous oxide and their isotopes • A tool for determining changes to the Southern Ocean carbon dioxide sink using atmospheric and ocean carbon cycle modelling that incorporates the best available integrated data set for atmospheric carbon dioxide, carbon dioxide isotopes, oxygen/nitrogen	• Modelling of carbon, water and energy cycles in Australian landscapes indicates that 2.2 billion tonnes of carbon is taken up by plants per year • Analysis of global emissions shows a 5.9 per cent increase in global carbon dioxide emissions from fossil-fuel burning and cement production in 2010 – the highest annual growth rate since 2003 • Measurements of greenhouse gas changes over the past few millennia using polar ice indicates there has been a 20 per cent increase in atmospheric nitrous oxide since 1750 mostly due to fertiliser use • A gap in the global carbon dioxide network was filled through expansion of the Southern Ocean atmospheric carbon dioxide observation network. This will help researchers clarify whether growing greenhouse gases and depletion of Antarctic stratospheric ozone is affecting the efficiency of the Southern Ocean's carbon dioxide sink	9-12
Atmosphere and land surface	**Land and air (observations and processes)** *Improving our understanding and modelling of greenhouse gas and aerosol flows between the land and the atmosphere Understanding the atmospheric response to these changes*	• Evaluation of climate feedbacks associated with IPCC Fourth Assessment Report models operating under different timescales (interannual, decadal, and climate change) and evaluation of feedbacks in response to different factors, including solar, ozone and carbon dioxide changes • Reduction of the large uncertainty in the climatic effects of aerosols (microscopic airborne particles) in the Australian and broader Indo-Pacific region by combining aerosol modelling and observations • A step-change improvement in land surface models (in particular the Australian land surface model CABLE–SLI) by using the regional variation of critical biophysical and canopy structural parameters derived from remote sensing	• For the first time, researchers have evaluations for model water vapour, vertical temperature, and surface snow and sea ice feedbacks across the full set of timescales – seasonal, from year to year, from decade to decade and climate change feedbacks • Analysis of atmosphere-ocean climate simulations suggests that aerosol changes (principally originating from the northern hemisphere) offset the effects of increasing greenhouse gases, which would otherwise be causing a decrease in rainfall in north Western Australia • An observational network indicates a clear seasonality in northern Australian atmospheric aerosols and will help refine model simulations and answer questions about the effects of the expected global decrease in aerosol over the next few decades • Observations from the OzFlux network suggest climate change may affect plant photosynthesis and respiration differently and therefore change the balance of ecosystem carbon exchange	13-16
Coasts and oceans	**Coasts and oceans** *Observing changes, understanding processes and developing projections*	• An improved and expanded ocean climate observing system via partnership with the Centre for Australian Weather and Climate Research, Australia's Integrated Marine Observing System and international partners	• Observations from ocean gliders in the boundary current region off eastern Australia strongly suggest that eddies live for several years and can transport Bass Strait water some 3,000km to south-west Australia	17-20

Key climate research theme	Research program area	Our targets	Key science outcomes	Pages
		• Improved data return from the Argo Float array through better use of satellite communications • Improved data streams delivered by deep water gliders and implementation of a strategy to monitor the East Australian Current (Australia's major boundary current) • Insight into fundamental uncertainties limiting our ability to understand and predict climate and to detect and interpret change • An assessment of how Australia's regional seas and the Southern Ocean influence carbon dioxide uptake and storage, and the relevance to the global carbon budget • Understanding how ocean acidification is developing in the Australian region so we can understand how our ecosystems are responding to the change	• Analysis of salinity (salt concentrations) in the global ocean during the past 50 years shows that patterns of salinity are changing and indicates that global rainfall and evaporation – the water cycle – has changed • Examination of data collected over the past few decades from the Southern Ocean has found evidence of a small reduction in the efficiency of the ocean carbon dioxide uptake in winter months, consistent with a weakening of the Southern Ocean sink. Related work also identified how physical processes, including ocean currents and winds, combine to produce regions in the Southern Ocean where water containing carbon dioxide produced by humans is carried into the deep ocean	
Water	**Modes of climate variability and change** *Focusing on the hydrological cycle, and its possible changes*	• Analysis of simulations submitted to the Coupled Model Intercomparison Project 5 (CMIP5) and preliminary evaluation of Australian Community Climate and Earth-System Simulator (ACCESS) simulations of tropical processes, including the Australian monsoon. • Development of prototype probabilistic near-term projections over Australia for research purposes, and for possible incorporation into products as part of the 2014 national climate change projections • Improved understanding of mechanisms responsible for inter-decadal change, reducing the range of uncertainty from previous projections • Understanding of the changes in southern hemisphere large-scale extratropical variability, in particular the Southern Annular Mode and its role in rainfall changes over Australia • Examination of the changes in the El Niño - Southern Oscillation and the Walker Circulation in the next generation of climate models (CMIP5) to determine if the conclusions drawn from earlier models are robust • Examination of the Walker Circulation under different types of external forcing to further clarify why the Circulation has weakened in recent decades • Examination of changes in the Hadley Circulation (large scale circulation of rising air in the tropics and descending air in the subtropics) • Examination of whether central Pacific El Niño events become more frequent under global warming in ACCESS and CMIP5 models • Determination of whether the Indian Ocean Dipole and El Niño - Southern Oscillation impacts are asymmetric with respects to positive and negative phases • Determination of the role of tropical and extratropical variability in the Australian drought-breaking process, and how this may change under global warming • Determination of the impacts of long-term mean state change on tropical variability	• Comparison of newer climate model simulations with observational data sets from 1980 to 1999 found the majority can simulate the Australian Monsoon's switch in low-level winds from pre-monsoonal Easterlies to monsoonal Westerlies better than the previous generation of global climate models • Comparison of the latest climate modelling tools shows that southern hemisphere winter circulation changes have been driven by temperature deviations from the long-term average that are largely due to increasing greenhouse gases • Comparison of earlier and newer climate change models and the development of near-term projections for Australia reduced some of the uncertainty that exists in projections for the next 10-20 years – this information will be added to the next round of national climate projections • Analysis of projections produced by 46 global climate models confirmed that future greenhouse gas emissions will have a strong impact on the climate of the southern hemisphere and the effects will be offset by ozone recovery to a small degree • Quantification of differences in aspects of El Niño - Southern Oscillation in the earlier and newer model simulation runs will help researchers better understand the Walker Circulation under different conditions and further clarify why it has weakened in recent decades • Observations and climate model simulations have shown that the positive Indian Ocean Dipole affects bushfire risk and severe droughts over south-east Australia	21-26

Key climate research theme	Research program area	Our targets	Key science outcomes	Pages
An Australian climate modelling system	**Earth systems modelling and data integration** *Modelling tools that can replicate the Earth's systems and feedbacks*	• Submission of coupled model results to be used by the IPCC Fifth Assessment Report • Further simulations prioritised following consultation with key collaborators and stakeholders • Incorporation/inclusion of atmospheric chemistry processes in ACCESS to describe Southern Hemispheric radiative forcing • Use of inventories to drive ACCESS predictions • Use ACCESS to determine the significance of long-lived greenhouse gases, aerosols and reactive gases as drivers of climate change in the Australian region and southern hemisphere	• Comparison of earlier and newer climate change models and the delivery of ACCESS climate change simulations and model output fields to CMIP5. This international project provides critical input for the upcoming IPCC Fifth Assessment Report for attribution and projection of climate change • Performance of the ACCESS simulations rank in the upper level of models internationally • The ACCESS model projects that for a scenario assuming concerted international efforts to reduce greenhouse gas emissions, temperatures averaged over the globe will stabilise at about 2°C warmer than present by late this century. If there was no emission reduction effort and rapid fossil-fuel based industrialisation in the developing world, the model projects continued warming throughout the century to reach about 4°C warmer than present by 2100 • Evaluation of global aerosol models indicates that the parameters used to calculate the aerosol optical properties may need to include information on the aging of smoke plumes that affect the aerosol chemical composition and size distributions	27-30
Climate projections, including extremes	**Australia's future climate**	• Understanding of how Australia's climate is going to change regionally, and the methods by which regional projections are made. • Improved robustness in estimates of global averaged and regional (around Australia) sea-level rise • Improved capability to project assessments of the coastal impacts of climate change • Assessment of available downscaling methods (i.e. methods to obtain regional and local scale details from broad scale projected changes) to decide the best approach for operational use as part of a national projections service • Web portal for accessing information about future climate extremes • Assessment of the influence of climate change on eastern seaboard rainfall events and evaluation of the reliability of climate projections for extreme weather events • Identification of how well climate models represent the climatology of closed lows and cold fronts • Understanding of how these systems may change in frequency or intensity, in the future • Improved BoM Statistical Downscaling Model to deliver projections across the Australian continent for key impact variables (rainfall, temperatures) with a 0.05° resolution for the entire 21st century based on CMIP5 simulations	• Research confirmed key drivers of sea-level change and that 90 per cent of the change in energy (heat) stored in the climate system resides in the ocean • ACCSP collaborative international research found that the two largest contributions to observed sea-level rise since 1972 came from ocean thermal expansion (about 40 per cent) and glacier melting (another 35 per cent). The remaining sea-level rise comes from changes in the ice sheets and land storage in reservoirs and extraction of groundwater from aquifers • Preparation for the next national climate projections show consistent projections for a decline in winter and spring rainfall across southern Australia and uncertain changes in summer and autumn rainfall in most regions in a future warmer climate • Key research and projections for extreme climate are expected to be available online in late 2012 • Climate modelling to investigate the influence of climate change on severe weather events across the Eastern Seaboard of Australia suggests that in a warmer climate a reduction in the number of heavy rainfall and river inflow events could occur due to fewer East Coast Lows	31-38

Key climate research theme	Research program area	Our targets	Key science outcomes	Pages
		• Production of a high-quality homogenous dataset of tropical cyclones over the Australian region for application in a variety of assessments of climatic extremes • Projection maps of changes in 24-hour rainfall extremes in the main population centres of Australia in 2050 under the A2 emissions scenario • Return-level/period curves for extreme rainfall through synthesis of existing dynamical and new statistical downscaling studies at a variety of spatial and temporal scales for different regions of Australia	• The BoM's Statistical Downscaling Model provided high-resolution regional projections to agriculture sectors and infrastructure planners that use hydrological modelling for future water management purposes • Data for all cyclones in the Australian Tropical Cyclone database from 1970 were recovered from various archived sources and the data examined and standardised to give a much more consistent analysis of cyclone characteristics (such as intensity) • Analysis of extreme rainfall observations and projections from global and regional climate models for current and future (2050) climates suggests, for example, that what is currently a rare (a one in 100 year event) rainfall event in Adelaide may become more frequent (a one in 30 year event) under climate change.	
Communication	**Communication and coordination** *Communicating the outcomes delivered by ACCSP* *Managing and co-ordinating the ACCSP*	• Effective management of the ACCSP • Oversight of annual review and planning • Implementation of the ACCSP strategic communication plan	• ACCSP science addressed national climate change priorities and the outcomes of the science were communicated in a timely manner to key decision makers and the wider community	39-40

Key climate research theme: Greenhouse gases

A key challenge is to track, understand and predict changes in greenhouse gas levels, and in the natural stocks and flows of carbon.

This is important due to the uncertainty about the future capacity of forests, soils and oceans to store carbon – with recent research suggesting a weakening in the Southern Ocean's capacity.

There is also uncertainty about how climate change might affect methane and nitrous oxide emissions, such as those from agricultural activities.

A greater focus is needed on how rising temperatures, changing moisture availability, and altered fire regimes, for example, will affect the capacity of vegetation and land to act as a carbon sink. Ocean and terrestrial carbon cycle research is critical to inform discussions and negotiations on national and global emissions reduction targets.

Table 3: In 2011-12, the ACCSP's *Global and regional carbon budgets program* contributed to improving our understanding of the source of greenhouse gases and key carbon sinks.

Research program area	Project title	Our Targets	What was delivered
Global & regional carbon budgets	**1.1 The Australian continental carbon balance**	• The carbon balance of the Australian continent for 1990-2009 (including its component sink and source fluxes) measurements and model outputs from Australian and global analyses	• A paper on the Australian terrestrial net carbon balance published to *Biogeosciences Discussions* as part of the global REgional Carbon Cycle Assessment and Processes (RECAPP) effort • A paper on multiple observation sets for reducing uncertainty in Australia's terrestrial carbon and water cycles published to *Biogeosciences Discussions* • Analysis of sensitivities to describe the response of the Australian carbon balance to variations in rainfall, temperature, carbon dioxide radiation and wind speed. A paper for *Hydrology and Earth System Science* is in preparation • A detailed comparison of multiple remotely sensed data sets for vegetation cover, describing leaf area index and fraction of absorbed photosynthetically-active radiation. A paper for remote sensing and environment is in preparation • Data on continental carbon fluxes due to land use change from the National Carbon Accounting System have been incorporated into the budget analyses • Greenhouse gas datasets analysed from the Australian observational network including Gunn Point (NT), Cape Grim (Tas), Cape Ferguson (Qld) and Otway (Vic)
	1.2 Global Carbon Project	• An understanding of global and regional patterns of carbon sources and sinks, what drives them, and ways to manage carbon to stabilise atmospheric carbon dioxide and other greenhouse gases	• The global balance of the exchanges (incomes and losses) of carbon between the carbon reservoirs or between one specific loop (e.g. atmosphere ↔ biosphere) of the carbon cycle for 1960-2010 • Carbon dioxide analyses, data and graphics online: www.globalcarbonproject.org/carbonbudget • Global communication effort – coordinated press releases from various institutions around the world • Global methane budget for 1960-2008 • Paper on new global methane budget submitted to *Nature Geoscience* • Regional carbon dioxide budgets produced as part of RECCAP • Paper on the Australian continental carbon balance and processes submitted to *Biogeosciences* • Paper on the carbon budget of Southeast Asia to be submitted to *Biogeosciences* • Editing of special issue on RECCAP syntheses in *Biogeosciences* in progress • Initial compilation of datasets on the size of carbon pools that accumulate or release carbon in collaboration with a newly established consortium of collaborators

Research program area	Project title	Our Targets	What was delivered
	1.3 Land and ocean carbon feedbacks in the palaeo record	• An estimate of the sensitivity of greenhouse gas changes to decadal and centennial changes in climate by modelling ice core and firn (air in compacted snow) in measurements of carbon	• New ice core measurements of carbon dioxide, methane, nitrous oxide and their isotopes, resolving changes during climate variations over the past two millennia published in *Nature Geoscience* • New data presented at conferences and made available to modellers of the carbon cycle and climate (e.g. for the IPCC Fifth Assessment Report runs) via databases (e.g. World Data Centre for Greenhouse Gases) • Simulations of the measured gas changes forced by climate variations, generated by climate carbon models from CSIRO and the Palaeo Carbon Modelling Intercomparison Project • Comparison of measurements with climate-carbon model simulations and attribution of causes of carbon dioxide and methane changes published in *Atmospheric Chemistry and Physics* and firn air measurements and model simulations for the past century published in *Atmospheric Chemistry and Physics*
	1.4 Southern Ocean carbon dioxide sink	• A tool for determining the magnitude and temporal behaviour of the Southern Ocean carbon dioxide sink using atmospheric and ocean carbon cycle modelling that incorporates the best available integrated data set for atmospheric, carbon dioxide, oxygen and nitrogen isotopes over the Southern Ocean	• Comprehensive, precise and integrated data set for atmospheric carbon dioxide, oxygen, and nitrogen over the Southern Ocean • The most accurate estimate to date of the current magnitude of Southern Ocean carbon dioxide sink and detection, using past long-term data, of decadal changes in the long-term Southern Ocean carbon dioxide sink • Preliminary paper drafted for submission to *Global Biogeochemical Cycles* or *Geophysical Research Letters* on model-data comparisons of oceanic sources and sinks of carbon dioxide in the Southern Ocean using high-precision atmospheric carbon dioxide measurements at Macquarie Island

Science highlights

Is our landscape losing or gaining carbon?

ACCSP researchers are answering this question by developing and testing a model of linked carbon, water and energy cycles in Australian landscapes. The model is used to find out how much land carbon is lost or gained through plant and soil 'breathing' in response to variable climate and rising carbon dioxide. Effects of fires, erosion and deforestation are also considered. CSIRO researcher Dr Vanessa Haverd said the project focuses on the variability of carbon flows in space and time for the past two decades, and how this period compares with the past 200 years. Results will help climate change policy makers understand if more carbon can be taken up by the Australian landscape and how stable it is in the face of climate variability. It will also help them understand if carbon stored in the land during periods of high plant growth will be released in subsequent dry periods. Results so far indicate:

- On average, 2 billion tonnes of carbon was taken up by plants per year from 1990-2011;
- Grassy vegetation (which dominates in dry and savanna-dominated regions) accounts for about 56 per cent of the uptake of carbon and woody vegetation (which dominates in wet and forested regions) accounts for about 44 per cent of carbon uptake across Australia;
- In wet (high-growth) years, the Australian biosphere 'breathes in' a vast amount of carbon from the atmosphere, exceeding the total human-induced greenhouse gas emissions;
- In dry years, the biosphere 'breathes out' nearly equal amounts of carbon back to the atmosphere – the variations seen from wet to dry years are associated with Australia's naturally highly variable climate;
- The above variability is accompanied by a long-term trend of increasing plant production due to CO_2 fertilisation.

This is a highlight of project 1.1 in Table 3.

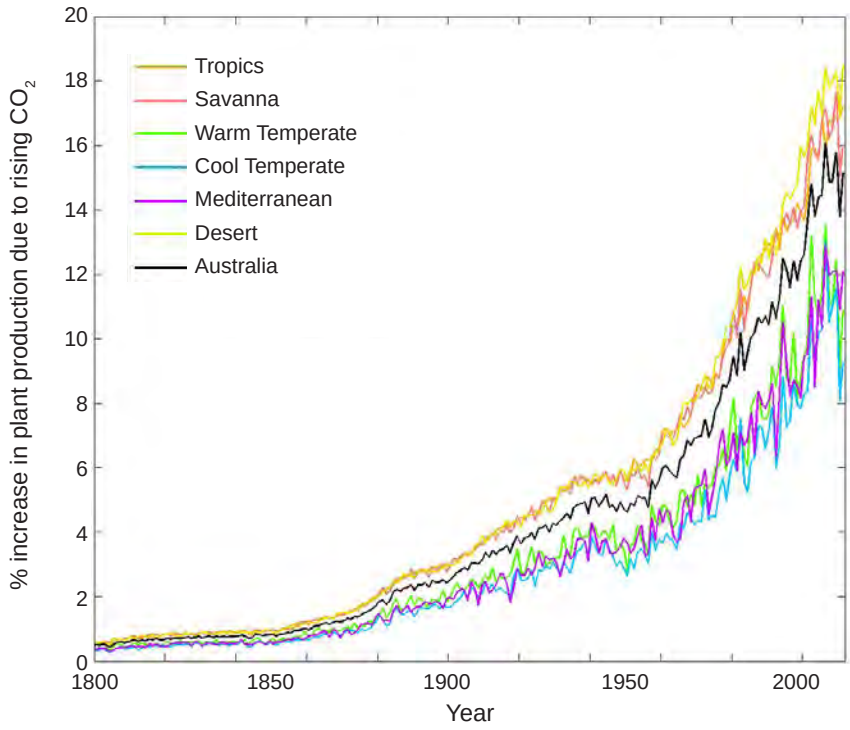


Figure 2. Fractional increase in plant production across the Australian landscape due to carbon dioxide fertilisation. The increase in plant production is larger in the Tropics, Savanna and Desert regions than the Temperate and 'Mediterranean' regions. For Australia as a whole, increased carbon dioxide in 2011 contribute an estimated 15 per cent increase in plant production relative to pre-industrial times. Other factors, such as rainfall changes, also affect plant production and are not shown here.

Global emissions rebound after GFC

Analysis of annual global emissions found that the impact of the Global Financial Crisis (GFC) in 2008-09 was short lived with carbon emissions rebounding to record levels soon after. Global carbon dioxide emissions from fossil-fuel burning grew 5.9 per cent in 2010. CSIRO researchers Dr Pep Canadell and Dr Michael Raupach said this is the highest annual growth rate since 2003. The growth seen in 2010 wipes out the 1.4 per cent GFC-induced drop in emissions recorded in 2009. This rebound puts global carbon dioxide emissions back on the same high-growth path that they were on before the GFC. The impact of the GFC was short-lived due to strong emissions growth in emerging economies, a return to emissions growth in developed economies, and an increase in the amount of fossil fuels used to produce each dollar of wealth in the world economy. The researchers will continue to analyse global carbon dioxide emissions to determine whether the trend of increasing global emissions will keep global warming under 2°C.

This is a highlight of project 1.2 in Table 3.

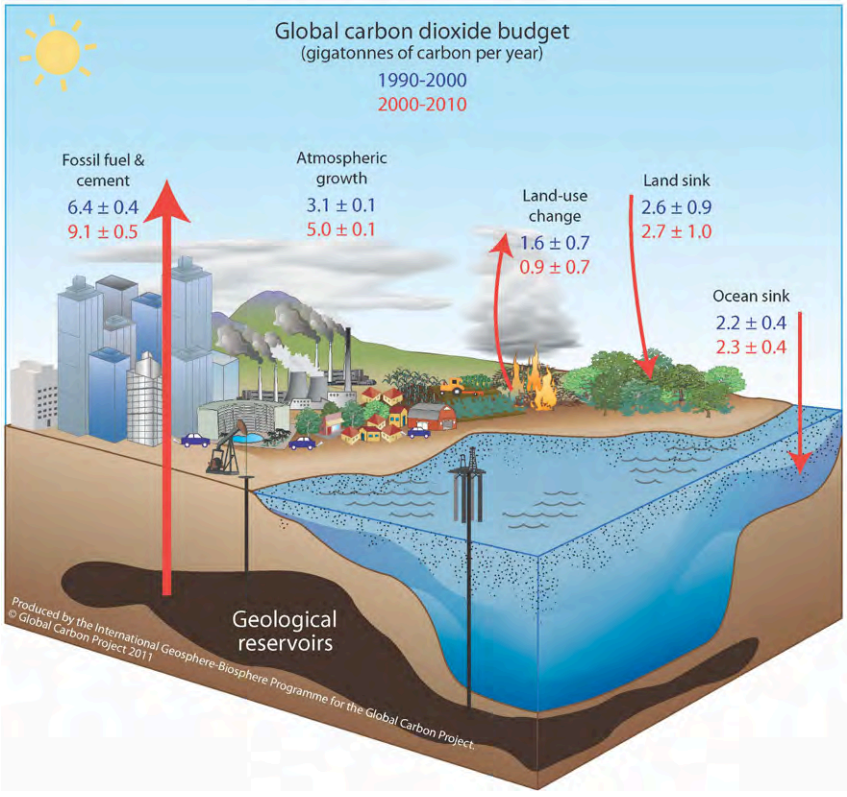


Figure 3. The global carbon budget for 1990-2000 and 2000-2010. The GFC showed little impact on the trend in increasing global carbon dioxide emissions that we saw for most of the 2000s. The growth in carbon dioxide emissions in 2010 wiped out the 1.4 per cent GFC-induced drop in emissions recorded in 2009. This rebound puts global carbon dioxide emissions back on the high-growth path it was on before the GFC.

New insights into atmospheric composition changes

Using new and existing measurements of greenhouse gases and their isotopes from the best available ice core and firn air (air in compacted snow) in Antarctica and Greenland, researchers have gained new insights into the changes to the atmosphere during the industrial period and the millennia beforehand. These observations help fill in the gaps with recent atmospheric composition records which are relatively short and are dominated by human-induced greenhouse gas emissions. Measuring greenhouse gas changes over the past few millennia using polar ice has enabled researchers to identify the causes of these changes and improve model prediction of trace gas behaviour in a future, warmer world.

Some key findings from CSIRO researcher Dr David Etheridge and his team include:

- There has been a 20 per cent increase in atmospheric nitrous oxide since 1750, most of which is due to fertiliser use;
- Measurements of carbon dioxide from a new ice core from the West Antarctic Ice Sheet have confirmed some of the main changes observed in Law Dome ice from the Australian Antarctic Science Program – they are variations of 5-10 ppm during the Medieval Warm Period climate events and the Little Ice Age, followed by a steady increase during the industrial period to levels not observed for two million years or more;
- A record of carbon monoxide concentration in the northern hemisphere from Greenland firn air has shown a decline in emissions since the 1970s;
- The first isotopic history of CFC (chlorofluorocarbon-12) has been produced from air samples from Greenland firn. This record traces the human-generated source and stratospheric sink of this gas which is both a strong greenhouse gas and depletes ozone; and
- The El Niño – Southern Oscillation climate variations have influenced methane sources (wetlands and biomass burning) over the past 300 years.

This is a highlight of project 1.3 in Table 3.

Carbon dioxide observation network expanded

A gap in the global carbon dioxide network was filled through expansion of the Southern Ocean atmospheric carbon dioxide observation network. This will help researchers to clarify whether growing greenhouse gases and depletion of Antarctic stratospheric ozone is affecting the efficiency of the Southern Ocean's carbon dioxide sink. A high precision atmospheric carbon dioxide analyser (called 'LoFlo' and developed by CSIRO) was installed at the World Meteorological Organization/Global Atmospheric Watch program station at Baring Head at the southern end of the North Island in New Zealand. Researcher Marcel van der Schoot said this station maintains the longest continuous carbon dioxide record in the Southern Hemisphere. A high precision carbon dioxide analyser (Cavity Ring Down Spectrometer) was also installed at the Australian Antarctic station at Casey. This is the first continuous atmospheric carbon dioxide monitoring capability to be established in the Australian Antarctic Territory and greatly extends the geographical coverage of the Southern Ocean atmospheric carbon dioxide observation network. It also provides the potential to investigate the relative contribution of the coastal Antarctic waters to the total Southern Ocean carbon dioxide sink.

The next step will be to consolidate this work to generate high precision modelling tools using existing data sets and atmospheric inversion modelling datasets to determine what, if any, changes have occurred in the ability of the Southern Ocean to efficiently store carbon dioxide generated by humans. This will help researchers to answer the following questions:

- Can we detect changes in Southern Ocean carbon dioxide flux using atmospheric carbon dioxide measurements and modelling?
- What is the current magnitude of the Southern Ocean carbon dioxide sink?
- How has it varied seasonally and interannually over past decades?

This is a highlight of project 1.4 in Table 3.

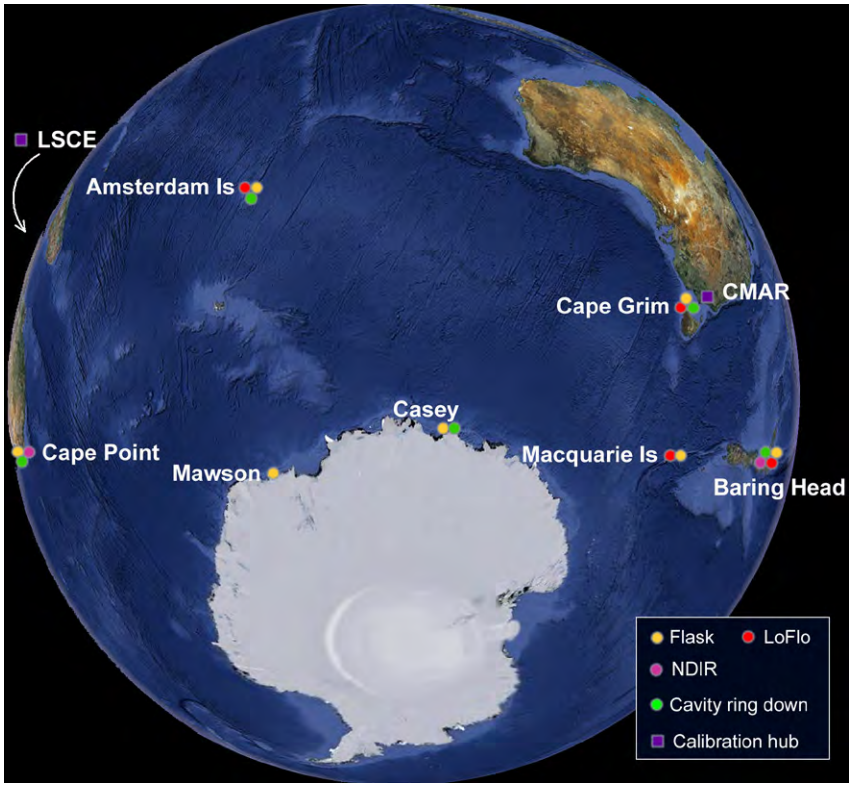


Figure 4. The Southern Ocean atmospheric carbon dioxide observation network. *Note: LSCE is the abbreviation for Laboratoire des Sciences du Climat et l'Environnement located in France.*

Key climate research theme: Atmosphere

A challenge is to improve our ability to predict atmospheric behaviour across various time scales. To do this, we need to address major gaps that remain in our understanding of atmospheric behaviour and its effects on the weather, the quality of the air we breathe, and the seasonal climate.

To address the atmosphere challenge, we need to improve our understanding of:

- Cloud dynamics and convection
- Atmospheric radiative transfer
- Cloud physics
- Aerosol-cloud interaction
- Atmospheric chemistry
- The changing teleconnections between the atmospheric/ocean phenomena that influence Australian climate (e.g. the El Niño - Southern Oscillation, the Sub-Tropical Ridge, the Indian Ocean Dipole, the Southern Annular Mode), and
- Stratospheric ozone depletion.

Table 4. In 2011-12, the ACCSP's Land and air (observations and processes) program helped increase our knowledge and understanding of atmospheric behaviour.

Research program area	Project title	Our targets	What was delivered
Land and air (observations and processes)	**2.1 Reducing uncertainties in climate projections by understanding, evaluating and comparing climate change feedbacks**	• Evaluation of climate feedbacks operating in IPCC Fourth Assessment Report models operating under different timescales (interannual, decadal, and climate change) and evaluation of feedbacks under different climate forcings, including solar, ozone and carbon dioxide	• Analysis of water vapour, lapse rate (vertical temperature profile), surface albedo and surface temperature feedback strength in Coupled Model Intercomparison Project 3 (CMIP3) models for the full range of timescales, including secular (long-term climate change), inter annual, decadal and seasonal • Analysis of the horizontal and vertical structure in CMIP3 models for seasonal, interannual, decadal, secular timescales • Paper on the atmospheric radiative feedbacks associated with climate variability and change published in *Climate Dynamics* • Conference presentation on understanding global climate feedbacks and how they vary with timescale at the WCRP Open Science Conference: Climate Research in Service to Society, 24-28 October 2011, in Colorado USA • Code developed to examine the so called 'rapid response' to such forcing: i.e. how climate responds on short timescales to these forcings (carbon dioxide, volcanic aerosols, solar changes and ozone changes)
	2.2 Aerosol and its impact on Australian climate	• Reduction of the large uncertainty in the climatic effects of aerosols in the Australian and broader Indo-Pacific region by combining aerosol modelling and observations	• Data from the CSIRO Aerosol Ground Station Network supplied to NASA for global dissemination through the Aerosol Robotic Network • Paper on biomass burning aerosol over Northern Australia published in the *Australian Meteorological and Oceanographic Journal* • Algorithm developed to derive aerosol optical depth over Australia from satellite (Advanced Along Track Scanning Radiometer) images • Paper on surface reflectance characteristics of continental Australia using satellite imagery • Paper on simulated effects of aerosols and greenhouse gases on recent and projected trends in circulation and rainfall published in *Atmospheric Chemistry and Physics*
	2.3 Improving CABLE–SLI (CSIRO model that calculates carbon, water and heat exchanges between the land surface and atmosphere) with spatially-distributed biophysical and standing structural parameters for a forest ecosystem	• A step-change improvement in land surface models (such as CABLE–SLI) by using the spatial distribution of critical biophysical and canopy structural parameters derived from remote sensing	• Expanded high-quality land-surface dataset from Tumbarumba (http://www.ozflux.org.au/) • New method for determining realistic parameter values for land surface models • Four journal articles and six conference papers published: 1. On the use of ground based and airborne lidar to derive parameter maps of stand structural parameters published in *Agricultural and Forest Meteorology*, *Geoscientific Model Development*, and presented at the Silvilaser Conference, Hobart 2. On the use of high resolution lidar and hyperspectral data to evaluate the sensitivity of net ecosystem exchange to stand structural and plant chemical properties published in *Global Biogeochemical Cycles*, and presented at the FLUXNET and Remote Sensing Open-Workshop in Berkeley, USA, and the International Symposium on Remote Sensing of the Environment, Sydney 3. On improving the constraints in land surface modelling by using the 3D spatial distribution of biophysical parameters derived from high resolution lidar and hyperspectral remote sensing published in *Agricultural and Forest Meteorology*, and presented at the FLUXNET and Remote Sensing Open-Workshop Berkeley, USA, and the International Symposium on Remote Sensing of the Environment, Sydney

Science highlights

Evaluating climate feedbacks across time

For the first time, researchers have evaluations for feedbacks associated with model water vapour, lapse rate, and surface snow and sea ice across the full set of timescales – seasonal, from year to year, from decade to decade and associated with climate change. Importantly, this evaluation includes not only the global and hemispheric averages of these, but also their horizontal and vertical distributions. This means that researchers can now compare models at seasonal and interannual timescales using estimates of datasets of the feedbacks operating in the real world. BoM researcher Dr Robert Colman said, in the analysis, he compared the model results with two such data sets. This comparison shows that on average, the climate models are able to reproduce the seasonal response with reasonable accuracy, as well as overall features of the interannual response. This provides important new tests for climate model feedbacks, allowing them to be evaluated at these timescales. However, it is important to extend the analysis to datasets from the newer generation of climate models and to include larger samples, using significantly longer time series of results – so that in particular decadal timescale feedbacks can be better estimated and compared with climate change feedbacks.

This is a highlight of project 2.1 in Table 4.

More about climate feedbacks

An example of a climate change feedback is the response of water vapour to warming: as the climate warms, extra water vapour in the atmosphere traps heat, further warming the planet – this is a positive feedback.

Researchers are unable to measure or evaluate most climate change feedbacks which operate at multi-decadal to centennial timescales because there are insufficient climate records for these long timescales. It is therefore important for researchers to evaluate these feedbacks by looking at observed processes operating at shorter timescales – for example, changes to water vapour that operate over the 'natural' variations in climate during a seasonal cycle, e.g. from summer to winter, from year to year or from decade to decade. These can then be compared and linked with climate change feedbacks.

Modelling and observations unlock aerosol secrets

Analysis of atmosphere-ocean climate simulations suggests that aerosol changes (principally in the northern hemisphere) offset the effects of increasing greenhouse gases, which would otherwise cause decreasing rainfall in north Western Australia. CSIRO researcher Dr Leon Rotstayn also found that the observed historical increase of rainfall in this region could not be explained by natural decadal variability. In other words, there appears to be a forced component to the rainfall increase. However, the modelling didn't capture the observed rainfall increase in simulations driven by changes in all forcing agents – due to cancellation between the effects of greenhouse gases and aerosols. Further research is needed to explain the reasons for this.

A clear seasonality in atmospheric aerosol has emerged using an observational network operated by Dr Ross Mitchell who has been measuring Australian aerosol over the past 15 years. These data are used to refine model simulations and will help answer questions about the effects of the expected global decrease in aerosol over the next few decades. Observational analysis has also identified 'super-absorbing' aerosols in northern Australia, probably linked with black carbon from widespread burning of vegetation. Reducing black carbon emissions is an option for tackling global warming so model sensitivity experiments will evaluate black carbon's role in forcing climate change in the Australian region.

This is a highlight of project 2.2 in Table 4.

More about aerosols

Aerosols are fine particles suspended in the atmosphere. Sources of human-generated aerosols include industry, motor vehicles and vegetation burning. Natural sources include volcanoes, dust storms and sea spray. Aerosols have long been known to exert a cooling effect on the climate, but the extent to which they do is one of the major uncertainties in climate change.

It is generally accepted that human-generated aerosols have substantially masked the warming effects of greenhouse gases. There is also increasing evidence that impacts of aerosols have masked changes in wind patterns and rainfall induced by increasing greenhouse gases. Human-generated aerosol emissions are projected to decrease sharply in the next few decades. This may accelerate the climatic effects of increasing greenhouse gases.

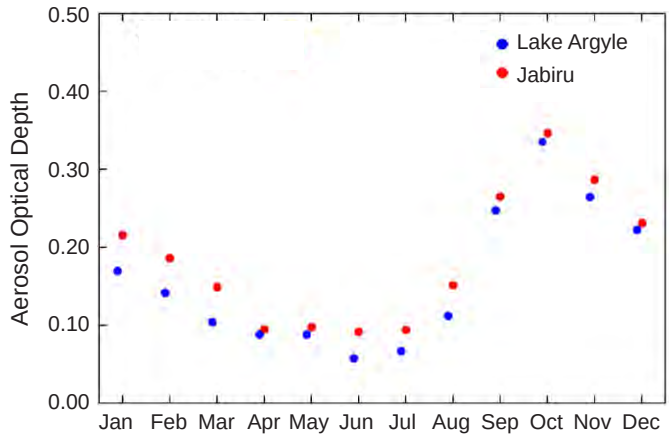


Figure 5. Monthly climatology of aerosol optical depth (a measure of the total amount of aerosol in an atmospheric column) at Lake Argyle in Western Australia and Jabiru in the Northern Territory demonstrates clear seasonality with a spring peak in aerosols. Current model simulations do not capture this, and under-predict the October maximum while over-predicting the early dry season (April-June) loading.

Figure 6. OzFlux (www.ozflux.org.au/) is part of a global network. Twenty-nine micrometeorological flux stations are located in Australia and New Zealand where exchanges of carbon dioxide, water vapour, and energy between land ecosystems and atmosphere are measured continuously at half hourly to hourly intervals.

Surface uptake and release of carbon and water

Observations continued from the OzFlux network of 29 micrometeorological flux stations in different ecosystem throughout Australia and New Zealand. They helped researchers work out how much carbon ecosystems can store and how much water is used for transpiration by plants and evaporation from soil and water bodies. CSIRO researchers Drs Eva van Gorsel and Ray Leuning used the observational data, remote sensing data, and modelling approaches to investigate carbon and water budgets over several time and spatial scales. Data analysis for the Tumbarumba site in NSW revealed that interannual variability of carbon and water exchange are caused primarily by variation in radiation, air and soil temperature, vapour pressure deficit, soil water content, and precipitation. They also found that the forest has turned into a source of carbon in one year due to secondary effects of weather conditions that broke the synchronisation of insects with parasites and predators. This resulted in an insect outbreak and moisture stress which restricted leaf regeneration after it was damaged. This research suggests that climate change and climate-induced changes may affect the plant photosynthesis and respiration and hence change the balance of ecosystem carbon exchange.

This is a highlight of project 2.3 in Table 4.

Key climate research theme:
Coasts and oceans

Sea level is rising, the oceans are warming and becoming more acidic, and currents are changing. This is placing stress on many marine species by changing their distribution and putting ecosystems at risk. In Australia, we are already seeing the impact of this on the corals of the Great Barrier Reef and the kelp forests off north-east Tasmania.

Many of Australia's coastal communities are vulnerable to coastal inundation, erosion and infrastructure damage from sea-level rise and extreme weather events associated with increased greenhouse gases in the atmosphere.

The challenge is to provide quality science-based information about the likely changes in sea level, storm surge and extreme weather events so that decision makers can manage the risks associated with, and minimise the consequences of, climate change.

To address these challenges, Australian science is needed in the following areas:

- The major impacts of sea-level rise, up-to-date assessments of past sea-level change, the factors contributing to sea-level rise, and how extreme sea-level events might change, what is known in each area and what research and observations are required to reduce the uncertainties in our understanding of sea-level rise so that more reliable projections can be made;
- Changes in sea-surface temperature and the circulation of the Southern, Indian and Pacific Oceans to help us understand their influence on rainfall patterns across southern Australia and the impacts for society and ecosystems; and
- The extent and timing of ocean acidification so we can monitor the impact on coral reefs in our tropics and primary producers in the high latitudes of the Southern Ocean.

Table 5. In 2011-12, the ACCSP's *Coasts and oceans program* increased our knowledge and understanding of the changes in our coasts and oceans.

Research program area	Project title	Our targets	What was delivered
Oceans and coasts (observations, processes, projections)	**3.1 Ocean climate processes: ocean monitoring to understand ocean control of the global and Australian climate**	• Improved and expanded ocean climate observing system via partnership with the Centre for Australian Weather and Climate Research, Australia's Integrated Marine Observing System, and international partners • Improved data return from the Argo Float array through increased use of Iridium satellite communications • Improved data streams delivered by deep water gliders and implementation of strategy to monitor the East Australian Current (Australia's major boundary current)	• Argo climate data set for real-time mapping of ocean heat and salinity changes, and sea level changes from increased warming and salinity • High–quality ocean glider data for the Coral and Tasman Seas • Oversight of the engineering design, building and deployment of the East Australian Current monitoring array • Leadership and presentation of a major international community white paper on ocean observations for climate at the World Climate Research Programme Open Science Conference, Denver, Colorado, USA in October 2011

Research program area	Project title	Our targets	What was delivered
	3.2 Ocean climate processes: understanding ocean change and influence on global and Australian climate	• Insight into fundamental uncertainties limiting our ability to understand and predict climate and to detect and interpret change	• Documentation of the spatial variability of mixing in the Southern Ocean and determination of the influence of topographic barriers (such as sea floor ridges) and deep passages on the dynamics of the Antarctic Circumpolar Current and the Southern Ocean overturning circulation • Measurement of the evolving ocean inventory of heat and freshwater along a deep oceanographic section between Perth and Antarctica and recovery of an array of current meter moorings deployed as part of a joint US-Australian project. Voyage and mooring recovery completed successfully in Jan-Feb 2012 • Analysis of new and existing full depth ocean profiles. This has shown significant changes in the temperature and salinity of Antarctic Bottom Water in the Southern Ocean and rapid transmission of these changes to the abyssal Pacific Ocean • Assessment of climate models shows more work is needed on simulations of the properties of Antarctic Bottom Water • Documentation of large scale changes in the earth hydrological cycle (precipitation and evaporation) using ocean salinity change and comparison of the observation-based results to climate models • Documentation of the ocean mixed layer processes that control the formation of key climate water masses and the pathways by which human-induced carbon and other gases are taken into the ocean interior • Communication of the latest science to government, industry and the public – (e.g. briefings to local, state and federal politicians in Hobart in Feb 2012, visits to schools, and public lectures at South Australian and Tasmanian museums)
	3.3 Ocean carbon and acidification	• An assessment of how Australia's regional seas and the Southern Ocean influence carbon dioxide uptake and storage, and the relevance to the global carbon budget • Insight into how ocean acidification is developing in the Australian region so we can understand how our ecosystems are responding to the change	• Quantification of the evolution of the Southern Ocean carbon sink based on historical data that shows a small decline in the wintertime uptake of carbon dioxide and a greater uptake over summer for the Atlantic sector due to increased biological production and stratification compared to the Indian and Pacific sectors • A new international surface ocean carbon atlas released with a major contribution through leadership of the Southern Ocean effort for all water south of 30ºS • New data on carbonate chemistry changes on the Great Barrier Reef at Heron Island in Queensland, and the development of improved models at reef scales to determine the exposure of reef communities to ocean acidification

Science highlights

Understanding and tracking ocean change

Australia's researchers are using new technologies and are collaborating here and overseas to collect and improve ocean monitoring of heat and freshwater (from rainfall and melting ice distributions and flows) around the world. CSIRO oceanographers Drs Susan Wijffels and Ken Ridgway said cutting-edge technologies and strong national and international cooperation are critical for observing global and regional oceans. In April 2012, the researchers set up a full-depth East Australian Current mooring array off Brisbane from the research vessel Southern Surveyor. The array of five moorings on the slope and abyssal region will help researchers understand how climate signals are communicated through the global ocean. It will also help them test model predictions of accelerated warming in these regions. The researchers also used ocean gliders in the boundary current region off eastern Australia. Powered by batteries, these instruments follow a zig-zag pattern through the water column for several months. They provide detailed horizontal sections (5km resolution) of ocean data – the Argo array and ship-based conductivity, temperature, and depth casts are unable to do this. Some observations from these gliders strongly suggest that eddies live for several years and, for example, can transport Bass Strait Water some 3,000km to south-west Australia. The researchers also sought the help of the United States and Australian navies to plug a critical gap in the Argo ocean and climate monitoring program caused by Somali pirates operating in the western Indian Ocean.

This is a highlight of project 3.1 in Table 5.

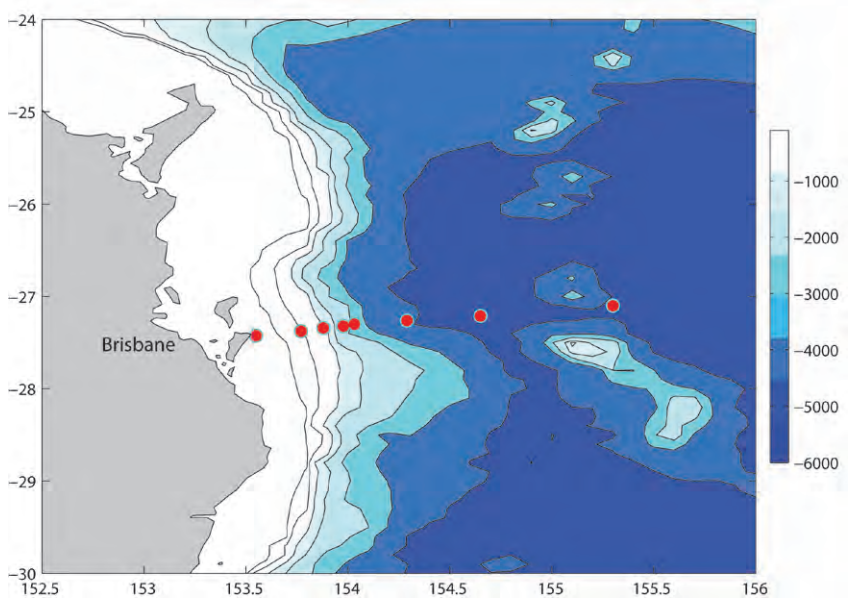


Figure 7. Location of the East Australian current mooring array off Brisbane. Contours show the ocean bathymetry (underwater depth of ocean floors, metres).

Figure 8. Deck crew on the research vessel *Southern Surveyor* preparing to install an acoustic velocity instrument as part of the East Australian Current mooring array.

Ocean salinity rainfall and evaporation changes

Salinity of the world's oceans is changing and indicates that global rainfall and evaporation – the water cycle – has changed. CSIRO researchers led by Dr Susan Wijffels have analysed patterns of salinity in the global ocean during the past 50 years and have found a clear fingerprint of climate change. By analysing salinity, and its relationship to rainfall and evaporation, they have determined that the water cycle has strengthened by 4 per cent from 1950-2000. Dry regions have become drier and wet regions have become wetter in response to global warming. This is double the response projected by the latest global climate models. With a projected temperature rise of 3ºC by the end of the century, the researchers estimate the water cycle could accelerate by a further 24 per cent and become much more intense – exacerbating the changes in dry regions and wet regions.

This is a highlight of project 3.2 in Table 5.

More about ocean salinity

Salinity in the ocean refers to the water's 'saltiness'. In oceanography, this is measured as grams of salt in a kilogram of water. For example, a salinity rating of 35 means for every kilogram of freshwater there is 35 grams of salt. The total amount of salt in the ocean is constant – rainfall and evaporation over the ocean do not add or remove salt from the ocean. They change the ratio of salt to freshwater. Therefore, the only way to change the ocean salinity is to add freshwater (increased rainfall over the ocean) which will make the ocean salinity decrease, or remove freshwater (increase evaporation) which will make the ocean salinity increase. This means measurements of salinity change are a direct measure of global rainfall/evaporation pattern changes.

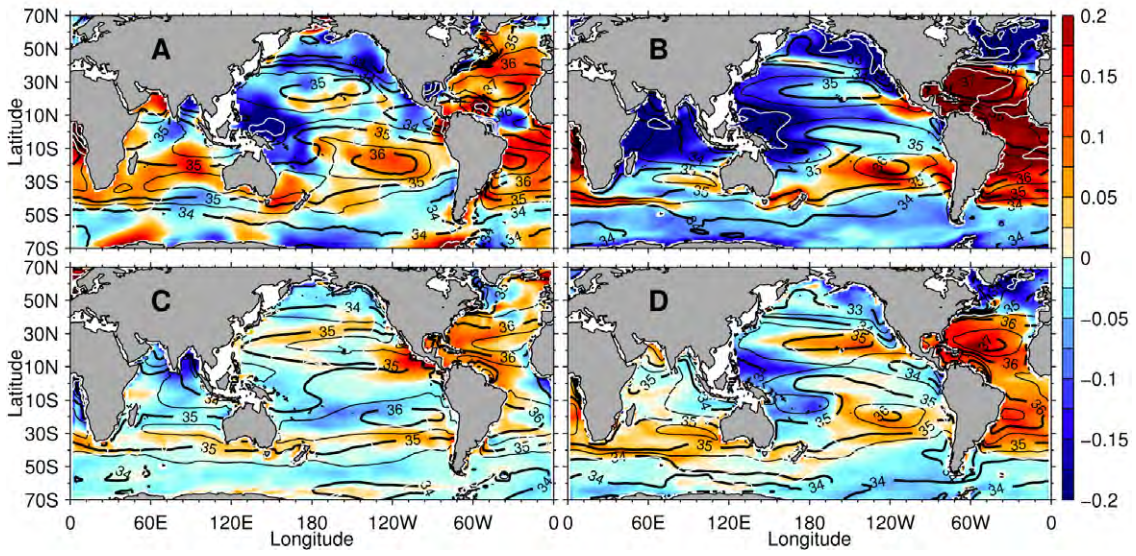


Figure 9. Patterns of 50-year surface salinity change reveal the ocean fingerprint of a strengthening water cycle in both observations and climate models. A) The contours show the observed average ocean salinity and the colours show the changes in ocean salinity between 1950 and 2000. B) This is the same as A, but shows an ocean model driven with a 5 per cent increase in the water cycle. It shows that the changes in the observed ocean salinity can be broadly explained by a 5 per cent increase in the water cycle. C) The same as A, for climate models that have a global warming of less than 0.5˚C. D) is the same as A but for a climate model that has a global warming of greater than 0.5˚C. A comparison of the observed change (A) with climate models (C and D) shows that low response climate models significantly underestimate the magnitude of the global water cycle change.

Understanding carbon uptake in the ocean

Observations and models are helping researchers determine how carbon dioxide is taken up and stored in Australia's regional seas and the Southern Ocean. CSIRO researchers Dr Andrew Lenton, Dr Bronte Tilbrook, and other colleagues examined data collected over the past few decades from the Southern Ocean. They found evidence of a small reduction in the efficiency of the ocean carbon dioxide uptake in winter months, consistent with a weakening Southern Ocean sink. However, the summer data revealed a different picture with the Atlantic sector of the Southern Ocean showing enhanced uptake due to increased biological production and the formation of more stable surface water layers compared to the Pacific and Indian Ocean sectors. In some related work, Dr Jean-Baptisse Sallée and ACCSP researchers identified how physical processes, including ocean currents and winds, combine to produce regions in the Southern Ocean where water containing carbon dioxide produced by humans is carried into the deep ocean. This is one of the major controls on the ocean's capacity to take up carbon dioxide from the atmosphere. The identification of the seasonal and regional patterns of ocean uptake and the mechanisms responsible are now beginning to emerge from the data. These are major steps forward in determining how the Southern Ocean uptake will respond to climate change and influence future levels of carbon dioxide in the atmosphere. The researchers are part of a collaborative international effort to enhance the Southern Ocean observing system for carbon dioxide and to expand the data available to researchers.

This is a highlight of project 3.3 in Table 5.

More about ocean uptake of emissions

The oceans are the major long-term sink for atmospheric carbon dioxide emissions, taking up about 30 per cent of the annual human-induced emissions. The Southern Ocean is considered to be one of the most important regions on earth for removing carbon dioxide from the atmosphere, and there are concerns the efficiency of the uptake by the ocean will decrease with climate change. A consequence of the uptake, however, is that it is causing ocean acidification, which could have serious implications for marine ecosystems in the Southern Ocean.

Key climate research theme: Water

Our demand for water is growing due to expanding urban areas, the need to feed a growing population, and the need to supply energy to more houses and businesses.

Australia is the driest inhabited continent even though some areas have annual rainfall of more than 1,200mm.

Our climate is highly variable across the continent, as well as from year to year. Extreme weather events such as tropical cyclones and East Coast Lows generate high rainfall events, often with significant impacts.

During recent decades, there has been a general trend towards:

- Increased spring and summer monsoonal rainfall across Australia's north;
- Higher than normal rainfall across central parts of the continent; and
- Decreased late autumn and winter rainfall across the south.

Climate model projections suggest long-term drying over southern areas during winter and over southern and eastern areas during spring.

Research indicates that long periods of diminished rainfall and increased evaporation may become more frequent as a result of climate change.

A challenge is to provide better information about likely future climates to help manage Australia's water resources in a changing environment.

The ACCSP is studying observed changes in rainfall, hydrology, evaporation and run-off to see if they can be attributed to climate change. Important areas include:

- Large scale drivers of inter-annual and decadal variability in the hydrological cycle – El Niño Southern Oscillation, the Indian Ocean Dipole, and the Southern Annular Mode;
- Links between climate change and the hydrological cycle, with particular reference to changes in the position and strength of the Sub-Tropical Ridge; and
- The influence of land-cover change on local and regional patterns of rainfall and evaporation.

Table 6. In 2011-12, the ACCSP's *Modes of climate variability and change* program addressed the above challenges and provided more information on current and likely rainfall changes to help manage water resources.

Research program area	Project title	Our targets	What was delivered
Modes of climate variability and change	**4.1 The Australian monsoon: processes, projections and extreme rainfall**	• Analysis of simulations submitted to the Coupled Model Intercomparison Project 5 (CMIP5) and preliminary evaluation of Australian Community Climate and Earth-System Simulator (ACCESS) simulations of tropical processes	• Papers on projected changes in tropical rainfall across northern Australia; in the Australian monsoon system as a large feature; in the extent of the Australian monsoon; and in extreme rainfall over tropical Australia published • 13 presentations on model representation of monsoon in current climate and projected changes given at local and international conferences • Preliminary evaluation of ACCESS tropical processes presentation at the ACCESS Model Evaluation workshop organised by the Centre for Australian Weather and Climate Research • Paper on intercomparison of six global climate models and their corresponding downscaled versions using CSIRO's Regional Climate Model (Conformal Cubic Atmospheric Model) runs over tropical Australia and analysis on their differences submitted to the *Journal of Geophysical Research*

Research program area	Project title	Our targets	What was delivered
	4.2 Detection and attribution of Australian climate change, rainfall and weather systems	• Disentanglement of the roles of greenhouse gas forcing and natural variability in the changing Australian rainfall and circulation • Determination of the effects of the three-way interactions between climate change trends, large-scale coupled ocean-atmosphere circulations and weather systems on rainfall • Determination of the extent to which the latest climate simulations (CMIP5 and particularly ACCESS) are skilful in reproducing the climate and rainfall trends in the 20th century • The likely projections of Australian climate change into the 21st century based on the collective skilful models	• Examination of changes and trends in the southern hemisphere winter Atmospheric circulation and southern Australian rainfall in CMIP5 models published in three journal papers and three conference papers • Changes and trends in southern hemisphere winter circulation, climate, rainfall and weather systems during the 21st century projected by collections of skilful CMIP5 models published in two journals and three conference papers • Evaluation of slow and intraseasonal teleconnections of inter-annual variability in the atmospheric circulation and their relationships to Australian rainfall and surface temperature for summer and winter in ensembles of CMIP5 models during the 20th century published in three journals and one conference paper • Paper on changes in slow and intraseasonal modes of variability and their relationships to Australian rainfall and surface temperature for summer and winter in 21st century projections with ensembles of skilful CMIP5 models published in *Climate Dynamics* • Examinations of the three-way interactions between climate change trends, large-scale coupled ocean-atmosphere circulations and weather systems in case studies of observed high and low monthly Australian rainfall published in two journals and four conference papers • Attribution of abnormal forcings associated with the changes in the mean climate of the southern hemisphere circulation in studies of high and low monthly rainfall published in two journals and three conference papers
	4.3 Near-term climate projections and predictions	• Development of prototype probabilistic near-term projections over Australia for research purposes, and for possible incorporation into products as part of the 2014 national climate change projections • Improved understanding of mechanisms responsible for inter-decadal change • Clarification and narrowing of the range of uncertainty from previous projections	• An assessment of ability of CMIP3 and available CMIP5 models to simulate decadal climate variability over Australia • Comparison of the magnitude of decadal variability to that of forced changes in both near-term and long-term projections over Australia • Quantification of the differences between the structures of near-term and long-term projections over Australia • Updated assessment of the role greenhouse gas and other external forcings have in trends in south-east Australian rainfall in recent decades, with specific consideration to the land-ocean temperature warming contrast and link to humidity • Updated assessment of the role of large-scale temperature patterns on simulated Australian rainfall inconsistencies, particularly the Pacific-Indian surface temperature differences in CMIP5 simulations • Prototype projections of temperature and rainfall, and other quantities, including uncertainties, for the coming decades

Research program area	Project title	Our targets	What was delivered
	4.4 Understanding southern hemisphere climate projections using sensitivity experiments with the ACCESS model	• Understanding of the changes in southern hemisphere large-scale extratropical variability, in particular the Southern Annular Mode and its role in rainfall changes over Australia	• Report on analysis of the impact of tropical and polar heating on the Southern Annular Mode (SAM) in ACCESS sea-surface temperature-forced perturbation experiments, including an evaluation of the model's ability to simulate the observed relationship between Australian climate and the SAM • Suite of ACCESS perturbation experiments with the atmospheric general circulation model component systematically forced by prescribed sea-surface temperatures • Long-term changes in atmospheric ozone and associated climate impacts in model projections submitted to the *Journal of Geophysical Research* • Climate system response to external forcings and climate change projections using Community Climate System Model version 4 published in the *Journal of Climate* • Presentations at the World Climate Research Programme's Open Science Conference in Denver, Oct 2011 and at the Australian Meteorological and Oceanographic Society's national conference in Sydney, Jan 2012
	4.5 Global warming, El Niño - Southern Oscillation, the Walker circulation, and the Hadley circulation	• Examination of the changes in the El Niño - Southern Oscillation and the Walker Circulation in the next generation of climate models to determine if the conclusions drawn from CMIP5 models are robust • Examination of the Walker Circulation under different types of external forcing to further clarify why the circulation has weakened in recent decades • Examination of changes in the Hadley Circulation • Examination of whether central Pacific El Niño events become more frequent under global warming in ACCESS and CMIP5 models	• Paper comparing projected changes in surface temperature, precipitation, mean sea-level pressure and wind-speed with the magnitude of year-to-year variability – partly due to El Niño - Southern Oscillation – in Coupled Model Intercomparison Project 5 models (CMIP5) models submitted to international journal • Additional paper on quantification of the differences in aspects of El Niño - Southern Oscillation in earlier and newer model simulation runs, and further investigation of changes in CMIP5 models in a larger number of scenarios for future greenhouse gases will be written up by the end of this year
	4.6 The response of the Indo-Pacific ocean variability to climate change and its impact on the Australian climate	• Determination of whether the Indian Ocean Dipole and El Niño - Southern Oscillation impacts are asymmetric with respects to positive and negative phases • Determination of the role of tropical and extratropical variability in the Australian drought-breaking process, and how this may change under global warming • Determination of the impacts of long-term mean state change on tropical variability	• Paper on the Southern Annular Mode contribution to the persistence of the multidecade-long drought over southwest Western Australia published in *Geophysical Research Letters* • Paper on south-east Australia autumn rainfall reduction submitted to the *Journal of Climate* • Paper on the impact of the Indian Ocean Dipole and ENSO teleconnection pathway on Australian climate submitted to the *Journal of Climate* • Paper on the south-east Queensland extreme summer rainfall published in *Geophysical Research Letters* • Paper on the impact of Indo-Pacific feedback interactions on ENSO dynamics submitted to the *Journal of Climate*

Science highlights

Testing newer model simulations of the tropics

Comparisons and testing of the latest climate models will help reduce some of the uncertainty in tropical rainfall projections from earlier models. Researchers looked at how the newer generation of models simulate large scale circulations affecting the Australian tropics, and the Australian monsoon in particular. They then applied this technique to the projections of unusually wet and dry monsoon seasons. BoM researcher Dr Aurel Moise said the Australian Monsoon is a critical phenomenon for Northern Australian in particular and wider Australia in general. Its marked seasonal cycle in atmospheric circulation patterns and rainfall has a significant influence on agriculture, ecosystem, industries, and human life. One of the features of the Australian monsoon is the switch in low level winds from pre-monsoonal easterlies to monsoonal westerlies. The majority of the newer models can simulate this switch in low-level winds better than the previous generation of global climate models. Further comparisons and testing of the newer models by researchers will help answer the following questions:

- What are the projected climate changes in the monsoon region?
- What are the projected changes in unusually wet and dry monsoon?
- How does the Australian Community Climate and Earth-System Simulator compare to other model simulations of tropical Australia?
- How different are the projections of the Australian monsoon from global climate models and regional climate models?
- Is the timing of the Australian monsoon onset or retreat expected to change?

This is a highlight of project 4.1 in Table 6.

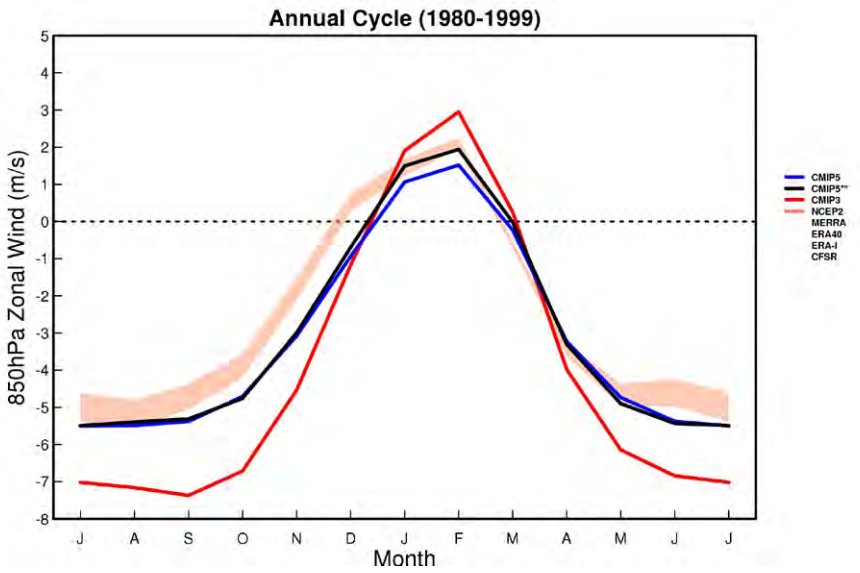


Figure 10. The newer generations of climate change model simulations were compared with observational data sets from 1980 to 1999. Winds above the dotted line are westerlies (monsoon season), below the line are easterlies. The majority of models can simulate the Australian Monsoon's switch from pre-monsoonal easterlies to monsoonal westerlies better than the previous generation of global climate models: The thick back line (average of newer models) is better placed within the pink band (observations) compared to the thick red line (previous generation of climate models).

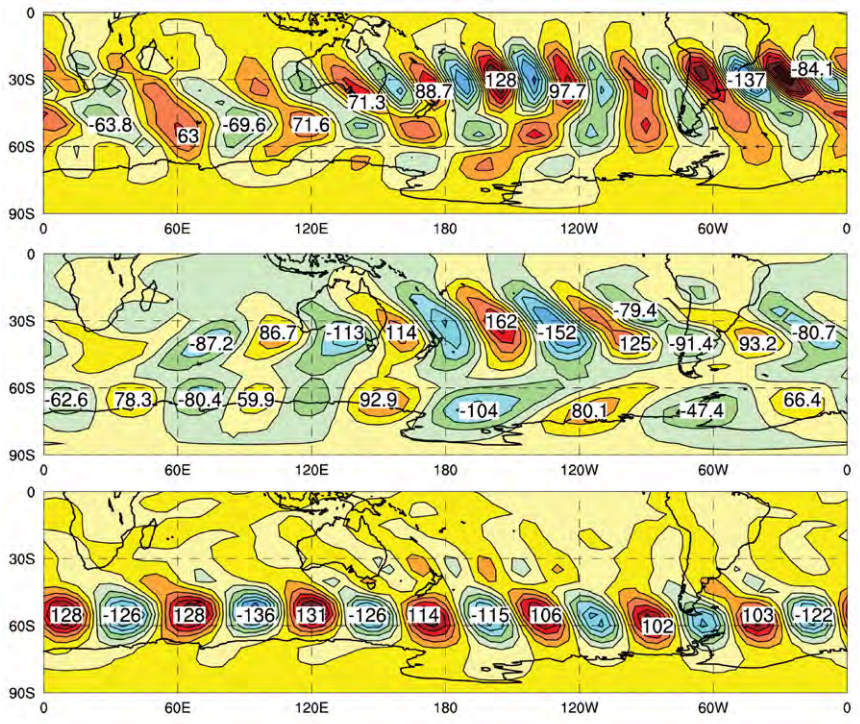


Figure 11. Leading Southern Hemisphere storm modes (the most dominant weather system) for October during the three periods 1949-68 (top), 1975-94 (middle) and 1997-2006 (bottom) They show that the highs and lows we would normally expect in spring are moving further south resulting in reduced rainfall in southern Australia.

Better understanding climate change interactions

New methods have been developed by researchers to help understand how the three-way interactions between climate change trends, large-scale coupled ocean-atmosphere circulations and weather systems influence rainfall. BoM researcher Dr Carsten Frederiksen and CSIRO researcher Dr Jorgen Frederiksen said they also assessed the latest climate models to see how successfully they captured the changes observed over recent decades and to assess their suitability for projection of future climates. Their results showed that the southern hemisphere winter circulation changes have been driven by temperature deviations from the long-term average that are largely due to increasing greenhouse gases. The climate models showed that increasing greenhouse emissions were likely to cause a continuing long-term downward trend in rainfall over southern Australia. They also showed that northwest cloudband and intraseasonal oscillation weather systems affecting rainfall over northwestern and central Australia have become more prevalent. The researchers intend to build on this work to better understand the underlying causes, drivers and mechanisms responsible for observed and projected Australian climate change in all four seasons. This work will provide more confidence in climate projections and help establish the causes of climate change in Australia.

This is a highlight of project 4.2 in Table 6.

Reducing uncertainty of near-term projections

Research focussed on improving the understanding of the causes of inter-decadal change and reducing some of the uncertainty that exists in projections for the next 10-20 years. Comparison of earlier and new climate change models and the development of near-term projections for Australia provided important results that will be incorporated in the next round of national climate projections. CSIRO researcher Dr Ian Watterson and his team also examined the drivers of recent climate change and the forced (human-induced) and unforced (natural climate system) variability in simulations of the coming decades from new generation climate change models. Some important findings are:

- Australian rainfall projections for the late 21st century vary between 22 models and are strongly related to warming in sea surface temperature;
- Interdecadal variability of Australian temperature and rainfall is similar in new and earlier models. For rainfall, it is similar to the magnitude of forced change from most models over the next few decades;
- Soil moisture is particularly variable in most of the models;
- New work has shown that for some regions that were previously categorised as 'models disagree on the sign of the change' are better interpreted as 'models agree that the changes are small' when compared to the interannual variability in the same location; and
- 21st century rainfall projections from 15 newer-generation climate models show reduced rain over most Australian land points but the rate at which rain reduces is greater in the first 30 years.

This is a highlight of project 4.3 in Table 6.

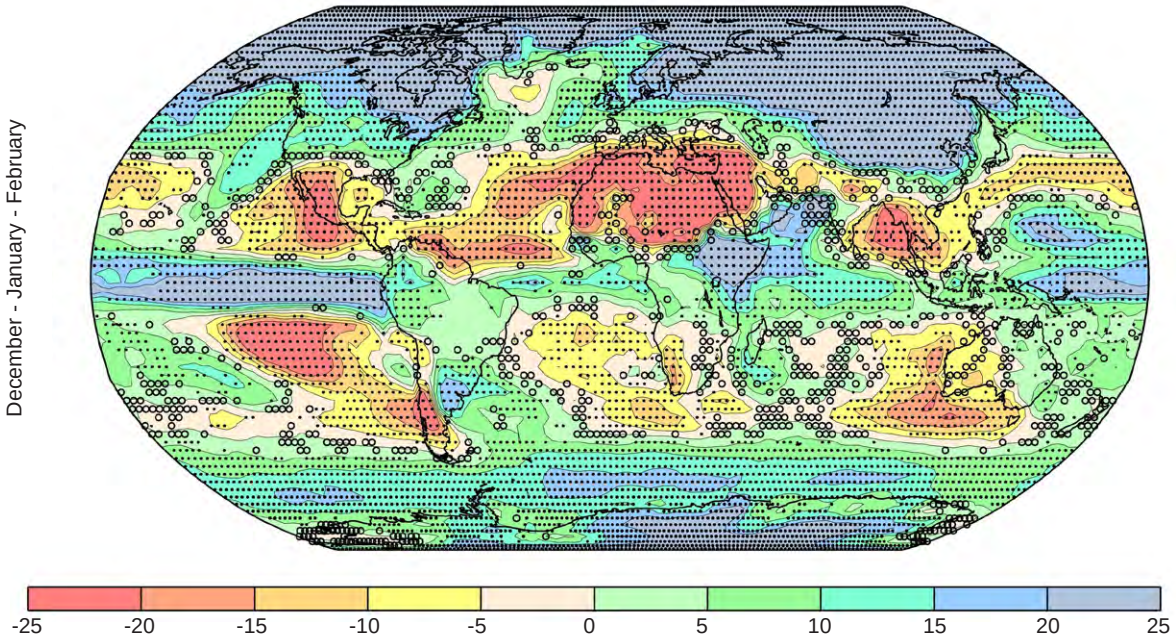


Figure 12. Rainfall projections for the late 21st Century for Dec-Feb in earlier (CMIP3) models under the AIB (a more integrated and ecological world) scenario. The stippling shows where models agree on the sign of the projected change. The small circles show where the models tend to agree that the projected change is small relative to variability between years in the same location. Under this scenario, over Australia a number of regions that were previously categorised as 'models disagree on the sign of the change' are better interpreted as 'models agree that the changes are small'.

Do greenhouse gases dominate climate change?

Researchers answered this question to help inform the IPCC Fifth Assessment Report and ensure that ozone recovery is included in all future assessment reports. Analysis of projections produced by 46 global climate models developed for the Climate Model Intercomparison Project Phase 5 confirmed that greenhouse gases will drive future climate change in summertime in the southern hemisphere in most emission scenarios. However, this new set of projections also suggests that the recovering ozone layer over Antarctica could influence the atmospheric circulation and rainfall as far north as Australia. BoM researcher Julie Arblaster said previous comparisons of earlier climate models found many did not include stratospheric ozone changes, therefore leaving out a crucial component of southern hemisphere climate change. The new set of projections showed that when warming from greenhouse gases is small, the southern hemisphere's mid-latitude summertime jet (an important fast-flowing narrow air current) could shift towards the equator and therefore reverse its trend to the south over the past few decades. In scenarios where there is strong global warming, the jet migrates away from the equator in the future. This means future greenhouse gas emissions will have a strong impact on the climate of the southern hemisphere and the effects will be offset by ozone recovery only to a small degree.

This is a highlight of project 4.4 in Table 6.

Better information for climate projection maps

New research improved the information used in climate projection maps. The Australian research investigated the projected changes in rainfall and compared the magnitude of the changes to interannual variability – including El Niño - Southern Oscillation (ENSO)-driven variability. Researcher Dr Scott Power and his colleagues found climate models tend to agree that in some regions projected changes are very small compared with the natural climate variability. In the past, such projections were misinterpreted as uncertain. More work will be carried out to help researchers understand how ENSO might change in the future due to human interference in the climate system. Collaborative research with scientists at Monash University will better understand what might happen to the Walker Circulation under different conditions and further clarify why it has weakened in recent decades.

This is a highlight of project 4.5 in Table 6.

More about the Walker Circulation

The Walker Circulation is one of the world's largest and most important wind systems. Changes in the Walker Circulation are linked to changes in rainfall, temperature, river flow, disease, crop yield and fire risk. Previous ACCSP research showed that the Walker Circulation was weaker in recent decades than at any other time in recorded history.

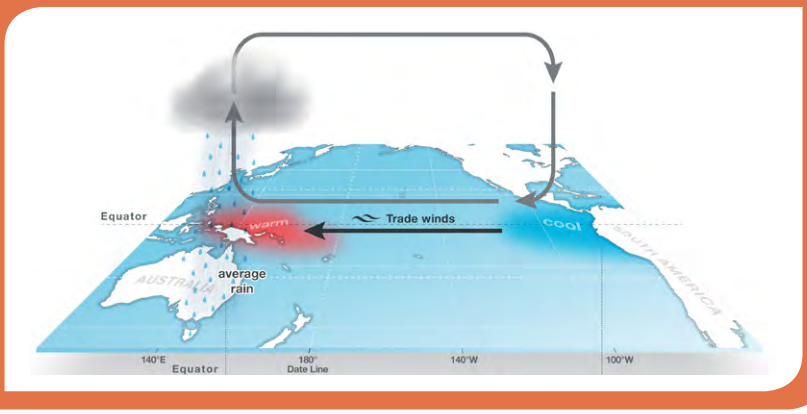


Figure 13. The Walker Circulation (see the grey arrows going in clockwise direction) comprises the equatorial easterly trade winds near the surface of the ocean, rising air in the west to the north of Australia, westerly winds in the upper atmosphere, and subsiding air in the east. The trade winds push the warm equatorial surface waters to the west, while at the same time driving the upwelling of cool waters in the east. The Walker Circulation is projected to weaken in response to global warming.

Large-scale climate events behind extreme weather

Observations and climate model simulations have shown that the positive Indian Ocean Dipole (IOD) affects bushfires and severe droughts over south-east Australia. Researchers Dr Wenju Cai, Peter van Rensch, and Tim Cowan said that the positive phase of the IOD (cooler-than-average sea-surface temperatures in the eastern Indian Ocean region) tends to have a greater impact on the south-east Australian climate than negative IOD events. This is because the eastern Indian Ocean cooling during positive IOD events is greater than the warming during negative IOD events. The cooling occurs when the upper, well mixed layer of the ocean is shallowing. During negative IOD events, the opposite occurs (the well mixed layer deepens) and the induced warming is smaller. Large cooling in the eastern Indian Ocean during a positive IOD event causes reduced rainfall from the eastern Indian Ocean to south-east Australia.

The researchers also found that although the Southern Annular Mode (SAM) is a dominant mode of variability influencing winter rainfall in southern Australia, the SAM has no impact on the autumn rainfall reduction over south-east Australia. A poleward expansion of the subtropical dry-zone is partly responsible.

The drought and flood areas over north-eastern Australia, including the heavily populated south-east Queensland, appear to be dominated by the phases of the Pacific Decadal Oscillation (PDO). All large flood events in south-east Queensland since 1900 have occurred when the PDO is at a negative phase and the Southern Oscillation Index (a tool that measures atmospheric pressure changes that can indicate changing weather patterns) is positive.

This is a highlight of project 4.6 in Table 6.

Key climate research theme:
An Australian modelling system

Climate models (simulators) have become increasingly sophisticated and are essential tools for understanding past and future changes in climate.

The fundamentals of models are based on the laws of physics and are represented as mathematical equations in a computer program. Models simulate the processes responsible for interactions of the atmosphere, oceans, land surfaces and ice. Future climate change can be simulated using projected greenhouse gas and aerosol emission scenarios.

As well as representing the atmosphere, ocean, land surface and sea-ice, many global climate models now include aerosols, the carbon cycle, and atmospheric chemistry so they can more realistically replicate the Earth's systems and feedbacks. These models are commonly known as 'Earth System Models'. Ultimately, social and economic systems may be included in the models to see the effect of policy changes at local and global scales.

Global climate models typically have grid-points spaced 100 to 200km apart, so they provide only broad-scale projections of climate change. Regional models (downscaling) can be driven by input from global climate models, and have grid-points with closer spacing. This enables them to 'zoom down' to regional and local scales giving better representation of regional processes such as weather and coastal and mountain effects.

A key challenge is to ensure that Australia develops and maintains a sophisticated modelling capacity.

The ACCSP provides support for developing the Australian Community Climate and Earth-System Simulator (ACCESS). ACCESS will deliver a new generation of numerical models to improve climate and weather research in Australia.

Table 7. In 2011-12, ACCSP researchers continued to improve the capability of ACCESS component models and integration of additional models into the system.

Research program area	Project title	Our targets	What was delivered
5. Earth systems modelling and data integration	**5.1 Development of the ACCESS coupled modelling system**	• Submission of coupled model results to be used by the IPCC Fifth Assessment Report • Further simulations prioritised following consultation with key collaborators and stakeholders	• Core CMIP5 simulations completed and published on the processed model output data on the National Computational Infrastructure Earth Systems Grid (ESG) node • Paper on the ACCESS coupled model: description, control climate and preliminary validation submitted to the *Australian Meteorological and Oceanography Journal* • Implementation of plan for additional simulations, using the ACCESS coupled model and consultation with key stakeholders from the Australian climate science and impacts communities • Set of targeted skill score metrics to enable objective evaluation of climate models, as well as metrics calculation tools and database – specifically, a set of tools to evaluate models against to a large number of observational datasets • Assessment of a comprehensive set of observation-based climatology data-sets to serve as the basis of the evaluation scheme – specifically, a collection of observational datasets has been quality controlled, standardised and made available to the climate research community • Climate diagnostics from CMIP5 historical simulations using ACCESS1.0 and 1.3, and some of the Mark3.6 versions evaluated and added to database of model spread and errors relative to observations. This database provides new benchmarking metrics for guiding ongoing model development • Enhancement of the ACCESS atmospheric component through the use of the single column model and full 3-D global model simulations, and through development of linkages with the MetOffice – specifically, participation in two international projects on simulation of clouds and convection and its impact on model behaviour • Summary of analysis studies and the status of parameterisation development and implementation was delivered to the Centre for Australian Weather and Climate Research (CAWCR) and seminars summarising ACCESS parameterisation development were given locally and overseas • Paper on AusCOM (the ACCESS ocean/sea ice model) prepared for submission to the *Australian Meteorological and Atmospheric Journal* • Collaborative AusCOM application studies with CAWCR published in the *Journal of Geophysical Research Oceans and Ocean Modelling* • Integration of components of the carbon cycle into the ACCESS system and experimentation with prescribed atmospheric concentrations to test surface carbon fluxes. Experiments were performed with an Earth system model including the effects of land use change

Research program area	Project title	Our targets	What was delivered
			• CABLE (land surface model) can now be run as a standalone model in a global configuration and its performance will be assessed for the release of CABLE v2.0 in late 2012 • Implementation of a data assimilation system for the ocean biogeochemical component of ACCESS (WOMBAT - world ocean model of biogeochemistry and trophic dynamics) to estimate the marine biological model parameters from ocean colour estimates of the surface phytoplankton concentrations • Quantification, using WOMBAT, of the link between dust variability in Australia and phytoplankton variability in the ocean around Australia • Integration and evaluation of tropospheric chemistry and aerosols in the ACCESS system, including non-carbon dioxide chemical cycles and emissions • Progress report on tropospheric chemistry and aerosols in the ACCESS system • Atmospheric and coupled configurations of the ACCESS1.0 and 1.3 CMIP5 models were transferred to the Centre of Excellence (CoE) Computational Modelling Systems Team. The ACCESS coupled model is now being run by CoE researchers to do further CMIP5 simulations • Assessment of the suitability of software engineering (OASIS-MCT) for use as the future coupler in the ACCESS modelling system • Quarterly briefing notes highlighting progress and issues submitted to key stakeholders
	5.2 Evaluation of ACCESS simulations of reactive and long-lived gases and aerosol in the Australian region	• Use of atmospheric chemistry processes in ACCESS to describe Southern Hemispheric radiative forcing • Use of inventories to drive ACCESS predictions • Use ACCESS to determine the significance of long-lived greenhouse gases, aerosols and reactive gases as drivers of radiative forcing in the Australian region and southern hemisphere	• Report that includes: 1. Progress on comparison of Global Model of Aerosol Processes (GLOMAP) and ACCESS UK-Unified Model (UK-UM) in the simulation of aerosol over the Australian continent including a sensitivity study of GLOMAP to fire emissions; 2. Progress on the determination of top-down regional methane budgets for Australia and the sensitivity of methane trends in the southern hemisphere to emissions and chemical processes; 3. Progress on a comprehensive assessment of the observed trends of ozone in the extra-tropical southern hemisphere troposphere and the sensitivity of ozone trends in the southern hemisphere to precursor emissions and chemical processes; and 4. Progress on the assessment of the sensitivity of background organic aerosol in the Australasian region precursor emissions and chemical processes. • Paper on ship engine exhaust emissions in waters around Australia published in *Air Quality and Climate Change*

Science highlights

ACCESS simulations used by the IPCC

A significant achievement this year for the Australian Community Climate and Earth-System Simulator (ACCESS) was delivering climate change simulations and model output fields to the Australian and international science communities through CMIP5 for use in climate analysis studies available to the *IPCC Fifth Assessment Report*. The ACCESS model comprises atmospheric, oceanic, sea ice and land surface components, and is the culmination of five years of development work and testing. CSIRO researcher Dr Tony Hirst said evaluation of the model indicates that its performance ranks in the upper level of models internationally.

For a scenario assuming concerted international efforts to reduce greenhouse gas emissions, the model predicts that temperatures averaged over the globe will stabilise at about 2°C warmer than present by late this century. For a scenario assuming no emission reduction effort and rapid fossil-fuel based industrialisation in the developing world, the model predicts continued warming throughout the century to reach about 4°C warmer than present by 2100. Further evaluation of the model solutions is underway in a range of ACCSP projects and others in the Australian research community. Additional simulations with the ACCESS model will be conducted next year to support Australian climate science.

Already, the ACCESS model is being run by researchers in the Centre of Excellence for Climate System Science to support research into the causes of climate change.

This is a highlight of project 5.1 in Table 7.

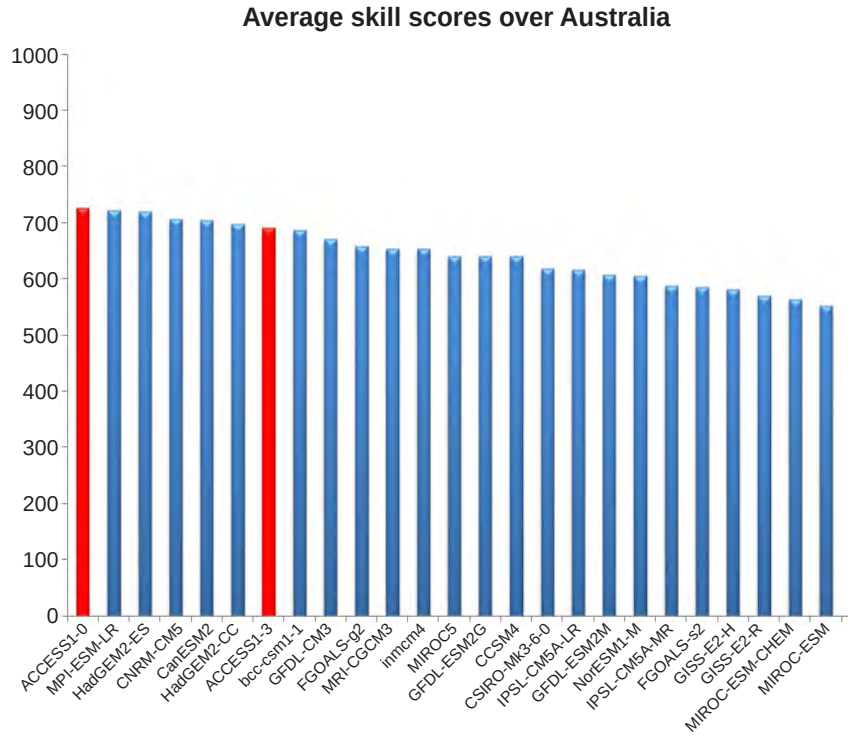


Figure 14. Model evaluation indicates that the performance of the ACCESS simulations rank in the upper level of models internationally. This figure shows average skill scores for a range of climate models over Australia, simulating the pattern and seasonal variation of three variables important for impact assessment studies (surface air temperature, precipitation and sea level pressure). A higher score means better performance. The two red bars show scores for two versions of the ACCESS model, showing that both versions of the ACCESS model perform in the upper level of models by this measure.

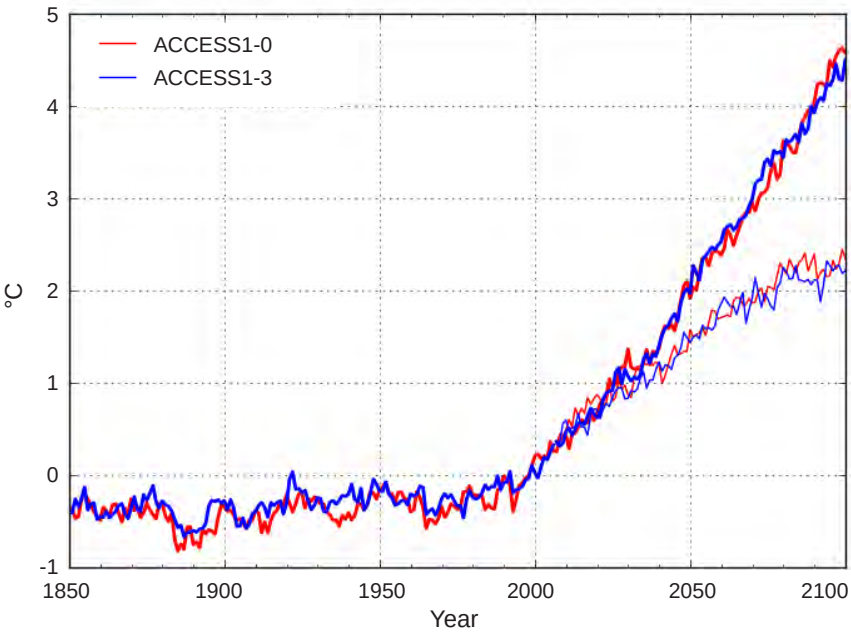
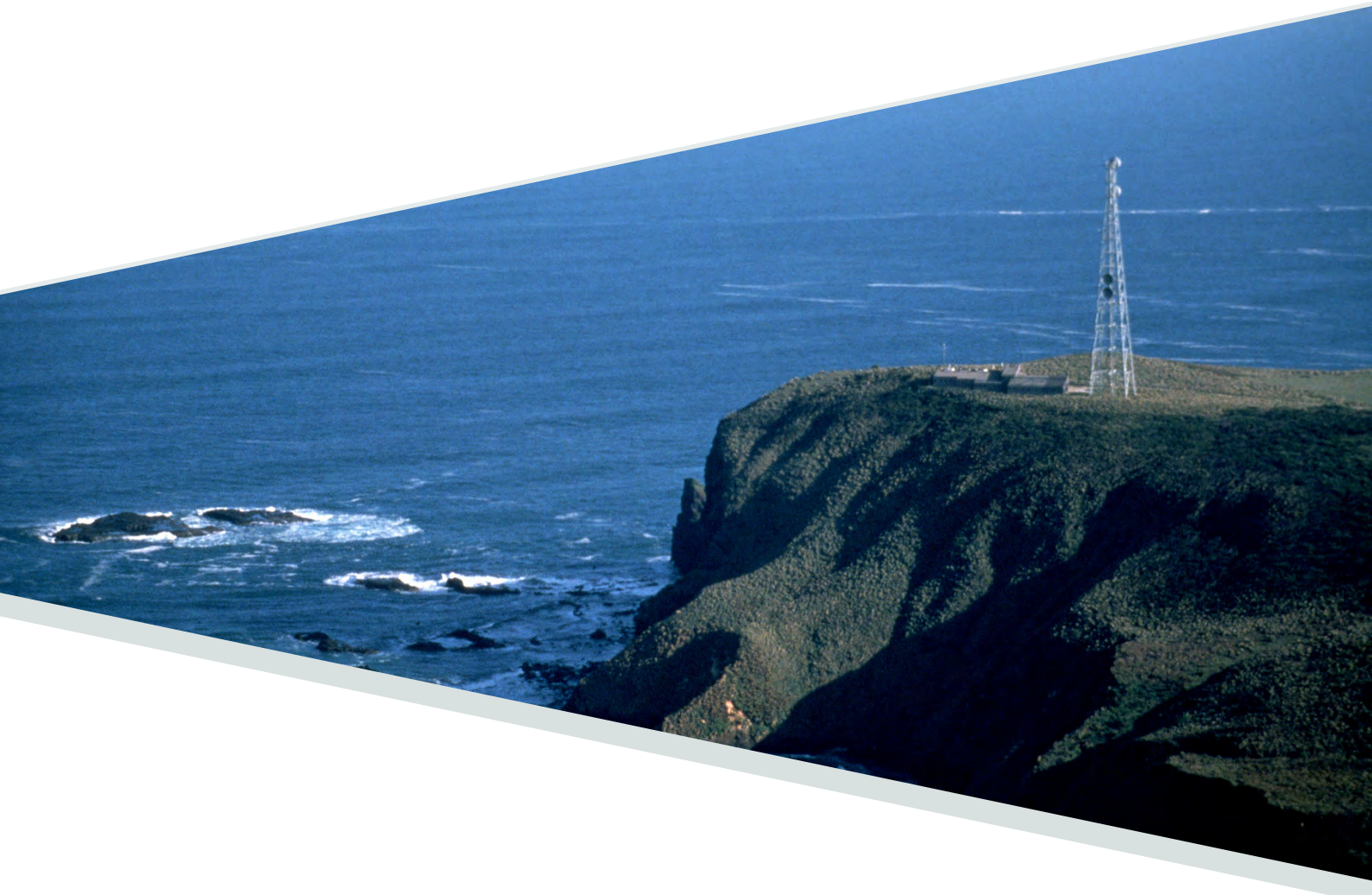


Figure 15. Surface air temperature (relative to the year 2000) averaged over the globe as simulated by two versions of the ACCESS model from 1850 to 2100. The simulations include historical changes in greenhouse gas concentrations, aerosol emissions, and solar radiation from 1850 to 2005, and future changes. The thick lines show a high emissions scenario (with continued warming throughout the century to reach about 4°C warmer than present by 2100. The thin lines show a low/intermediate emissions scenario with temperatures averaged over the globe to stabilise at about 2°C warmer than present by late in the century.

Getting global aerosol models right

Researchers evaluated the ability of global aerosol models to reproduce regional and short-term variations in aerosol concentrations by looking at the sensitivity of the models to fire emissions. Good comparisons between modelled and measured aerosol optical depth (a measure of the total amount of aerosol in the atmospheric column) could only be achieved when fire emissions were scaled up by 400 per cent. To achieve this scale of emissions, the number of fires and the amount of material they emit to the atmosphere would need to be considerably higher than actually occurs in nature. It is more likely that the parameters used in the models to calculate the aerosol optical properties will need to be adjusted. In particular, CSIRO researcher Dr Keywood said that the models should include information on the aging of smoke plumes that affect the aerosol chemical composition and size distributions. Both are important factors in calculating aerosol optical depth and will be the focus of future work. This will add to the body of knowledge that will help researchers better understand the effects of aerosols on climate variability.

This is a highlight of project 5.2 in Table 7.



Key climate research theme: Extremes

Extreme climate events include heat waves, cold snaps, tropical cyclones, storm surges, floods, droughts and bushfires. These events are, by their nature, rare. The rarer the event, (e.g. tropical cyclones, tornadoes), the more difficult it is to identify long-term changes, simply because there are fewer cases to evaluate.

Extreme climate events can have a serious impact on the environment and society, including loss of life, property and livelihoods. In recent years, the occurrence of extreme climate events and the associated damage has become highly visible, for example:

- **A severe and prolonged heat wave** (12-15°C above the seasonal average of 28-32°C) in late January and early February 2009 resulted in 374 more deaths in Victoria than would normally be expected during this time (Victorian Department of Human Services, 2009);
- **Black Saturday bushfires** on 7 February 2009 ravaged Victoria destroying more than 2,000 homes, burning more than 430,000 hectares of land, and causing death and destruction higher than any previous fire events in the recorded history of Australia;
- **Heavy rainfall** on 10 January 2011 caused widespread flash flooding in the Toowoomba city centre and the Lockyer Valley resulting in devastating loss of life and property followed by slow-onset flooding along the Brisbane river; and
- **Tropical cyclone Yasi** made landfall on Mission Beach in Queensland on 3 February 2011 and was one of the most powerful cyclones (rated category 5 with wind speeds of up to 205km per hour, gusts up to 285km per hour, and a 5m tidal surge) to be recorded since 1918.

While many extreme events are the result of natural climate variability, there is increasing evidence that the number and intensity of extreme events may be changing partly as a result of human influence on the climate.

Considerable research effort has gone into improving our understanding of what the future may hold in terms of extreme climate events. A key challenge is to provide access to the latest information on how extreme events are likely to vary under a changing climate.

Table 8. In 2011-12, the ACCSP's Australia's future climate program improved our understanding of extreme climate events and improved access to the latest key extreme climate information.

Research program area	Project title	Our targets	What was delivered
6. Australia's future climate	**6.1 Improved sea-level, wind-wave and storm surge projections**	• Improved robustness and estimates of global averaged and regional (around Australia) sea-level rise • Improved capability to project assessments of the coastal impacts of climate change	• Evaluation of techniques for estimating the regional distribution of sea-level and ocean volume rise and estimates of their regional distribution for recent periods. Data will be updated online (http://www.cmar.csiro.au/sealevel/) and a paper was published in 2011 • Paper on 20th century sea-level rise submitted to the *Journal of Climate* • Data for satellite-altimeter verification from Bass Strait and Storm Bay to improve altimeter sea-state readings • An initial assessment of Coupled Model Intercomparison Project 5 (CMIP5) global climate models for surface wave and coastal modelling applications and projections of surface waves for the Australian coast • Evaluation of hydrodynamic and coastal models for their suitability for resolving coastal processes and providing projections of a range of coastal impacts (including, e.g. finite volume models with unstructured grids and links to Simulating WAves Nearshore wave model) • Model simulations to project changes on extreme sea levels and currents in Australia based on above inputs

Research program area	Project title	Our targets	What was delivered
	6.2 Regional climate projections science, including downscaling	• Understanding of how Australia's climate is likely to change regionally, and the methods by which regional projections are made • Assessment of available downscaling methods to decide the best approach for operational use as part of a national projections service	• Paper on model evaluation and the implications of the CMIP5 results for Australian projections submitted to *Australian Meteorological and Oceanographic Journal*. A poster on this topic was also delivered at an international conference in March 2012 • Article on the Climate Futures projection approach published in *Climatic Change*. Climate Futures software was further developed and used in a Climate Synthesis workshop for the Hunter region in May 2012 • Plan prepared on how to perform national climate projections in 2013-14 using the CSIRO climate futures approach • Paper on comparing global climate models and downscaled results on extreme temperature and rainfall change has been drafted for journal submission. Report comparing the results of various downscaling methods for mean rainfall change has also been drafted. Both the paper and report provide recommendations on the use of downscaled projection results • Around 60 requests were met for tailored climate change projections for use in climate change risk assessments • Papers on improvements to probabilistic projection methods published in *Australian Meteorological and Oceanographic Journal* and submitted to *Climatic Change*
	6.3 Climate extremes portal	• Web portal for accessing information about future climate extremes	• Demonstration of prototype Australian map with regional summaries of projected changes in extreme events given to DCCEE in Canberra on 8 February 2012 • Prototype interactive tool for extreme temperature and rainfall projections (see above) • Website development based on expert consultation within CSIRO and BoM as well as drawing on information obtained from previous ACCSP-funded consultations • Guidance material: The portal has an intuitive interface, minimising the need for guidance material. Individual datasets are provided with both plain-English and detailed scientific descriptions of the methodologies used in their development. • Development of web portal which is expected to go live in late 2012 • Brochure promoting the portal and the DCCEE funding that underpins it which will be available when the website goes public
	6.4 The influence of climate change on extreme events associated with East Coast Lows	• Assessment of the influence of climate change on rainfall on the eastern seaboard of Australia and evaluation of the reliability of climate projections for extreme weather events from East coast lows	• Climatology of heavy rainfall events affecting the Eastern Seaboard with signatures that are related to East Coast Lows events • Evaluation of the existing upper level atmospheric flow diagnostic on risk of formation of East Coast Lows using the new rainfall climatology • Initial evaluation of the role of low-level instability in East Coast Low development • Paper on regional water projections for a range of different events, including extreme localised rainfall, extreme widespread rainfall and significant reservoir inflow events and comparison with climate model direct projections published in *Australian Meteorological and Oceanographic Journal* • Papers accepted for publication: Changes of the risk of extratropical cyclones in eastern Australia in *Journal of Climate* and Large-scale diagnostics of extratropical cyclogenesis in eastern Australia in *International Journal of Climatology*
	6.5 Trends and projected changes in cyclonic rainfall	• Identification of how well climate models represent the climatology of closed lows and cold fronts • Identification of how these systems will change in frequency or intensity, in the future • Understanding of the mechanisms underlying these changes	• Climatology of Australian region 'closed lows' based on the outputs from global and regional climate models • Projected changes in the occurrence of Australian region closed lows for future climates – identification of the causes underlying the changes has begun • Climatology of Australian region cold fronts based on the outputs from global and regional climate models • Projected changes in the occurrence of Australian region cold fronts for future climates • Paper under preparation on the projected changes in the Australian region for closed lows and cold fronts and their influence on precipitation

Research program area	Project title	Our targets	What was delivered
	6.6 Application of the Bureau of Meteorology statistical downscaling model to Coupled Model Intercomparison Project 5 models	• Improved Statistical Downscaling Model to deliver projections across the Australian continent for key impact variables (rainfall, temperatures) with a 0.05° resolution at a daily time-scale for the entire 21st century based on Coupled Model Intercomparison Project 5 simulations	• Improvements to Statistical Downscaling Model and delivery of projections across the Australian continent for use by agriculture sectors and infrastructure planners • Paper on BoM's statistical downscaling model gridded projections, including the interpolation between regions and the consistency between projections, for the 19th International Congress on Modelling and Simulation, Modelling and Simulation Society of Australia and New Zealand in December 2011 • Paper on the issue of variance underestimation in the analogue model and ways to improve this to be submitted to *Climate Research* • BoM's statistical downscaling model gridded projections and stations based data provided to nine users
	6.7 Tropical cyclone database repair	• High-quality homogenous dataset of tropical cyclones over the Australian region for application in a variety of assessments of climatic extremes • Recorded descriptions of data for the cyclones when it is possible	• Modification of the cyclone intensity parameters using the current DVORAK satellite image interpretation technique for all Australian cyclones in the satellite era • Quality control of the modified data by independent experts • Presentation of the homogenous (standardised) Australian cyclone database to Australia's climate change researchers • New technique of cyclone 'vortex specification' was added to the cyclone database to improve estimates of cyclone intensity in the database and provide more cyclone variables
	6.8 Projected changes in Australian rainfall extremes	• Projection maps of changes in 24-hour rainfall extremes in the main population centres of Australia in 2050 under the IPCC A2 emissions scenario • Return-level/period curves for extreme rainfall through synthesis of existing dynamical and new statistical downscaling studies at a variety of spatial and temporal scales for different regions of Australia	• Projection maps of changes in daily rainfall extremes in major population centres of Australia in 2050 under the A2 emissions scenario at a spatial resolution of 10 km or better • Paper describing the methodology for producing spatially consistent return-level/period curves, and associated uncertainty estimates, derived by synthesising dynamically and statistically downscaled rainfall extremes, under review for publishing in CSIRO Technical Report

Science highlights

The science behind rising sea levels

ACCSP and international researchers have confirmed that the two largest contributions to observed sea-level rise since 1972 came from ocean thermal expansion (about 40 per cent) and glacier melting (another 35 per cent). The remaining sea-level rise comes from changes in the ice sheets and land storage in reservoirs and extraction of groundwater from aquifers. CSIRO Wealth from Oceans Flagship researcher Dr John Church said sea levels are projected to rise for centuries to come. This has serious implications for 10 per cent of the world's population living in coastal areas less than 10 m above the sea level. To get a better understanding of the causes of sea level rises, the researchers looked at the world's sea-level and energy budgets and updated estimates of all contributing factors for the past few decades – including a new estimate of groundwater depletion. The researchers were able to evaluate the sea-level budget from 1972 to the present. They confirmed that sea-level rise and ocean warming had continued to increase up to the present time, along with increasing greenhouse gas concentrations. However, their work suggests that increases in aerosols from developing countries, and moderate volcanic activity, may have partially offset the forces of greenhouse gases over the past decade.

The researchers will continue to update time series of the observed sea-level rise and explore ways to improve the quality of the satellite data. They will also begin exploring the latest climate models' ability to project sea-level rise.

This is a highlight of project 6.1 in Table 8.

More about sea-level change

Sea levels are projected to rise for centuries with continuing greenhouse gas emissions. This potentially has serious implications for the 10 per cent of the world's population that live in coastal regions below 10 m elevation – with the majority located in urban centres. The impact of changing sea levels will be felt most through the combination of storm surges and extreme waves. It is the energy released by waves and tide and storm surge-induced currents, in addition to sea-level rise, that causes changes in coastal inundation and shoreline erosion.

Storm surges may increase or decrease in severity in the future depending on changes to local weather conditions. However, the magnitude of these storm surge changes has been found to be small compared to the globally-averaged projected rise in mean sea level.

Decision makers are using science from this project for local coastal planning and adaptation activities. For example, extreme sea levels calculated for Victoria underpinned a major impact and adaption assessment for Western Port Region Victoria (http://www.seccca.org.au/uploads/projects/Socio-Economic_Impacts_Report.pdf)

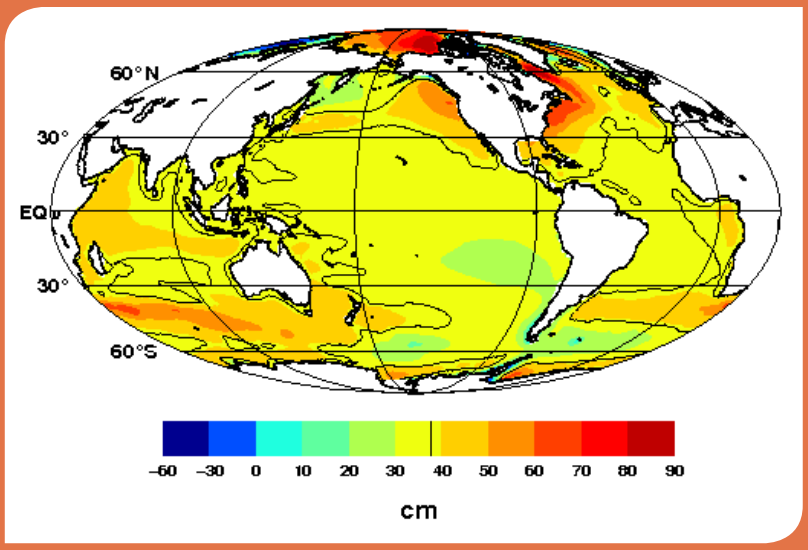


Figure 16. Projections of the regional distribution of sea-level change from 1990 to 2090. This distribution shows that sea-level relative to the land is projected to rise by an average of 38 cm across the globe. This rise will vary because of changes in ocean currents and the Earth's gravitational field from melting glaciers and ice sheets, and movement of the Earth's crust.

New projections reinforce results from earlier models

Preliminary analysis of new climate models shows very consistent projected temperature and rainfall changes over Australia between new and earlier versions. While there were some differences between the models, the projections consistently showed the tendency in a future warmer climate for a decline in cool season rainfall across southern Australia but less certain changes in summer rainfall in most regions. This work by CSIRO researcher Dr Penny Whetton and her team is critical for developing the scientific basis for the next round of Australian climate change projections that will be released in mid-2014. The new projections will be provided to users in a variety of formats and will be based on the latest global climate modelling and downscaling science. The researchers also continued to develop a new framework for simplifying the communication of climate change projections in the context of a rapidly growing mix of climate model and downscaled results. They also further developed the Australian *Climate Futures* software which simplifies the selection of climate scenarios for use in assessing the risk of climate change. The software is being used internally and will be made public when development is complete.

This is a highlight of project 6.2 in Table 8.

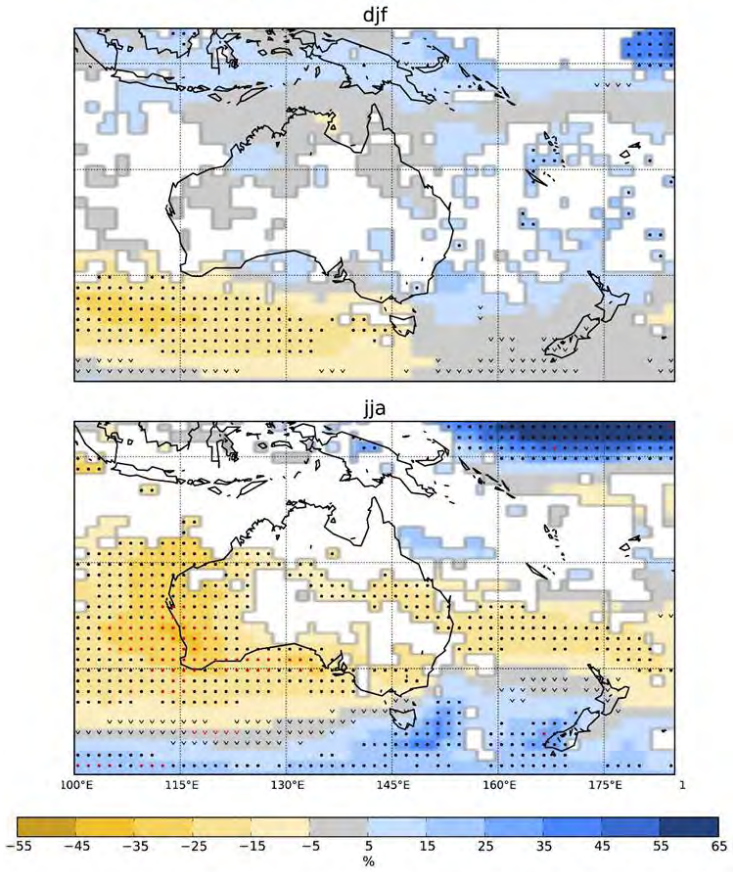


Figure 17. Comparison of projected rainfall change (see colour scale) and consistency between new generation models show rainfall (stippling) for summer (upper panel) and winter (lower panel). The projected change is for 2080-2099 relative to 1980-1999, under a high greenhouse gas emissions scenario. Dots indicate where the models agree on direction of change (>90 per cent red, >67 per cent black) and 'v's show agreement on little change. White areas show where the changes may be large but agreement on the direction of change is low. There is a strong indication of a decrease in winter rainfall in southern and western Australia.

Climate extremes research to come online

Key research and projections for extreme climate will soon be available online. A lot of research on climatic extremes has been undertaken in the past few years but there has been no central point for people to access this research. CSIRO researcher John Clarke said a website has been developed to hold this information in one place and to enable decision makers to access the information in three ways:

1. **Interactive map:** Users can find region-specific data by clicking on the area of interest on a map of Australia or by selecting a region from a drop-down list. Gridded data are displayed as a selectable overlay on the map. Other data are presented as clickable links under category headings (see below).
2. **Extreme Categories:** Information and datasets are provided through six categories each with a plain-English explanation of past trends and future projections and links to further information. The six categories are:
   a. Temperature Extremes
   b. Drought
   c. Flood
   d. Storms and Tropical Cyclones
   e. Fire Weather
   f. Coastal Extremes.
3. **Search:** Users can search for specific areas of interest by typing key words or phrases into a search box.

To ensure the climate extremes portal remains a useful resource well into the future, researchers will continue to modify and test it, and add the latest research. The portal is expected to be live from late 2012 at http://extremes.climatechangeinaustralia.gov.au

This is a highlight of project 6.3 in Table 8.

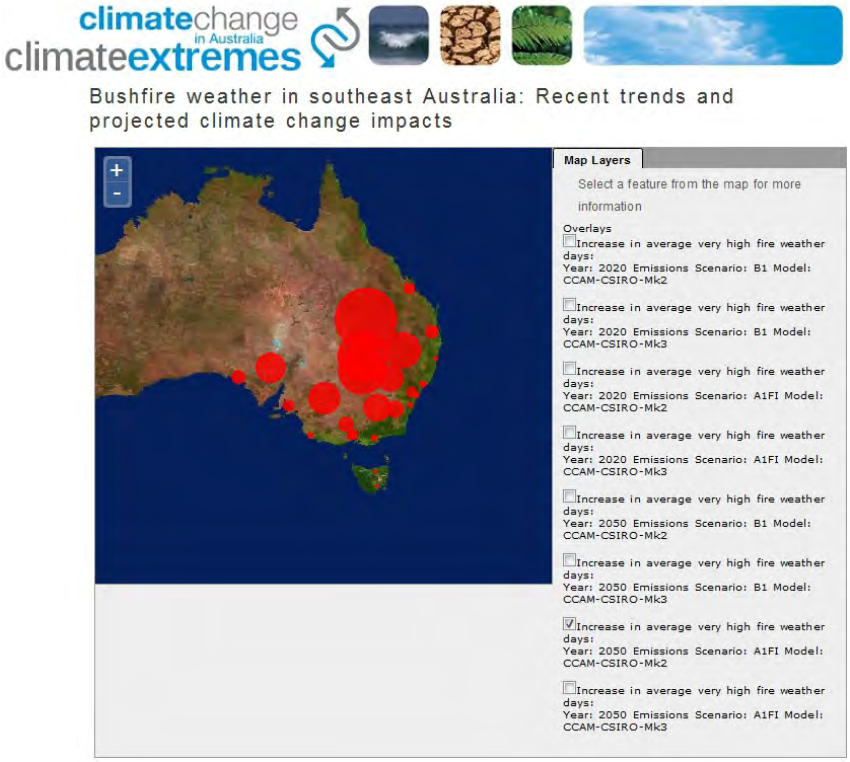


Figure 18. Example page of extreme fire weather data from the climate extremes online portal which will be available from late 2012 at http://extremes.climatechangeinaustralia.gov.au

How do East Coast Lows affect extreme rainfall?

Researchers addressed this question by using climate models to investigate the influence of climate change on severe weather events across the eastern seaboard of Australia – the most populated area in Australia. The research to date has shown a warmer climate is likely to reduce the frequency of East Coast Lows which cause the most extreme weather events. Dr Andrew Dowdy and his team investigated the expected changes in extreme rainfall events associated with the reduction in East Coast Lows projected by climate models. They analysed daily rainfall observations using a process tailored to East Coast Lows and high-quality river-flow data from BoM's Climate and Water Division to examine heavy rainfall and large river inflow events. The climate projections suggest that in a warmer climate:

- The rate of heavy rainfall and river inflow events is likely to be strongly influenced by changes in East Coast Low events;
- A reduction in the number of heavy rainfall and river inflow events could occur due to fewer East Coast Lows – but while an important factor, these storms are one of many relating to heavy rainfall occurrence in this region; and
- The results showed significant differences to rainfall projections taken directly from global climate models, highlighting the value of appropriate downscaling and understanding of regional rainfall mechanisms.

More research is needed into other impacts such as large wave and strong wind events. The researchers will also investigate lower-level atmospheric conditions and the role of oceanic processes and human-induced climate change on intense East Coast Lows.

Assessing cold front and closed low projections

Climate model simulations of cold fronts and closed lows across Australia helped researchers understand how rainfall producing systems may change under future climate conditions and how the changes will affect Australia's water supply. CSIRO researchers Dr Sally Lavender and Dr Debbie Abbs found two commonly-used models showed a distribution of cold fronts. However, one model slightly over estimated this and failed to capture any lows over the Tasman Sea. The same model also slightly underestimated the percentage of rainfall influenced by the combined closed lows and cold fronts and failed to capture the influence of closed lows over the far north of Australia. While both projections produced consistent decreases in cold fronts and associated rainfall in the south, the results including closed lows were inconclusive over land due to the large differences between the two models used.

This is a highlight of project 6.5 in Table 8.

More about cold fronts and closed lows

In the south of Australia, cold fronts provide a large proportion of the annual rainfall.

Closed low pressure systems, including tropical and extra-tropical cyclones, monsoon lows, east coast lows and cut-off lows are known to have a large influence on Australian rainfall. More than 60 per cent of annual rainfall in some regions, notably the northwest, can be attributed to these closed low systems.

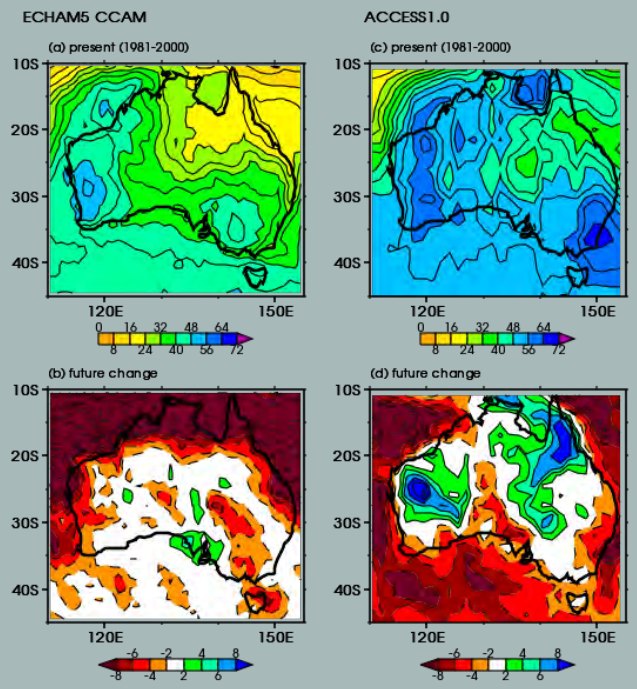


Figure 19. Model simulation of the annual percentage of rainfall due to closed lows and cold fronts in the current climate (1981 to 2000) using (a) Community Climate Atmosphere Model (CCAM) and (c) ACCESS1.0 simulations. The same models show the change in the annual percentage under future climate conditions for 2080 to 2099 in (b) CCAM and (d) ACCESS1.0. Both models suggest decrease in closed-low and cold-front influenced rainfall in coastal regions under future climate conditions. However, the results are inconclusive due to the large differences between the two models used.

High-quality projections available for regions

High-quality regional projections were developed and provided to agriculture sectors and infrastructure planners that use hydrological modelling for future water management purposes. BoM researcher Dr Bertrand Timbal said the BoM's Statistical Downscaling Model was developed because the relatively coarse resolution of global climate models is not sufficient for assessing the small scale impacts of climate change. The BoM's Statistical Downscaling Model is now being applied to all available climate change projections for key impact variables (rainfall, temperatures) and provide downscaled information on a 0.05 degree (one data point every 5km) grid across Australia. The data will continue to be provided on a case-by-case basis to a range of industries across Australia, e.g. hydrology, crop modelling, human health, natural environment, and energy and infrastructure management.

This is a highlight of project 6.6 in Table 8.

Tropical cyclone database gives better projections

Original data for all cyclones in the Australian Tropical Cyclone database were recovered from various archived sources. The data were examined to determine the cyclone parameter calculation methods and techniques that were used to calculate cyclone intensity numbers. BoM researcher Dr Hakeem Shaik said current DVORAK techniques were then used to homogenise (standardise) cyclone intensity values for all cyclones in the satellite era in the Western Australian, Northern Territory, and Queensland regions. Climate change researchers will be able to use the homogenised Australian database to detect and understand any trends in the number and intensity of tropical cyclones over the satellite era. Dr Shaik said a new technique of cyclone 'vortex specification' was also developed and added to the cyclone database. The cyclone vortex data improves estimates of cyclone intensity in the database and also provides additional cyclone variables (such as the size of the cyclonic circulation) for climate change studies.

This is a highlight of project 6.7 in Table 8.

More about the database

Australian tropical cyclone tracking has been carried out by BoM during the satellite era using a technique developed by Vernon Dvorak in 1973. The DVORAK technique estimates the intensity of a cyclone by examining the pattern and shape of clouds using visible and infrared satellite images.

The DVORAK technique is still commonly used among cyclone forecasters worldwide and has been continuously improved over time. However, this means that operational centres have used different parameters over time in their analysis, making it difficult to compare cyclones from different regions and times. By doing a consistent 'reanalysis' of the database, using the latest DVORAK parameters, a consistent picture can be built. It is important to have a homogeneous data set for researchers to evaluate the trends in cyclone climatology and prepare projections for climate change.

Rare rainfall events may become less rare

Analysis of extreme rainfall observations and projections from climate models for current and future (2050) climates suggests that what is currently a rare rainfall event might become a less rare event in the future. For example, the analysis of projections from global and regional climate models found that four out of the six models projected an increase of about 15 mm in the 100-year return level of annual maximum daily rainfall for Adelaide. CSIRO researcher Dr Aloke Phatak said this means that what is currently a rare (a one in 100 year event) event may become more frequent (a one in 30 year event) under climate change. The initial results of the analyses comparing return levels of annual maximum daily rainfalls in current and future climates for the other capital cities suggest:

- Darwin shows no change in extreme rainfall;
- Perth – two of the six models show strong decreases in 100-year return level of about 25 mm;
- Hobart – only one of six models show a strong increase in extreme rainfall;
- Canberra exhibits a moderate increase in return levels, with the 100-year event increasing by about 20 mm;
- Melbourne – one model suggests a decrease in return levels while the other shows no change; and
- Brisbane and Sydney, one model projected increases in extreme rainfall (about 30 mm), whereas others showed no change.

Global climate model projections of rainfall, and in particular, the intensity and frequency of extreme rainfall events, are much less consistent, mainly due to the coarse resolution and the way these models represent clouds, convection, and other local processes. Regional climate models describe atmospheric processes on a smaller scale and can produce projections of extreme rainfall at higher spatial resolutions that may be more realistic than those from global climate models. However, the variability in projections produced by global and regional models mean it will be important for researchers to continue comparing and combining results from many climate models to assess the reliability of future extreme rainfall projections.

This is a highlight of project 6.8 in Table 8.

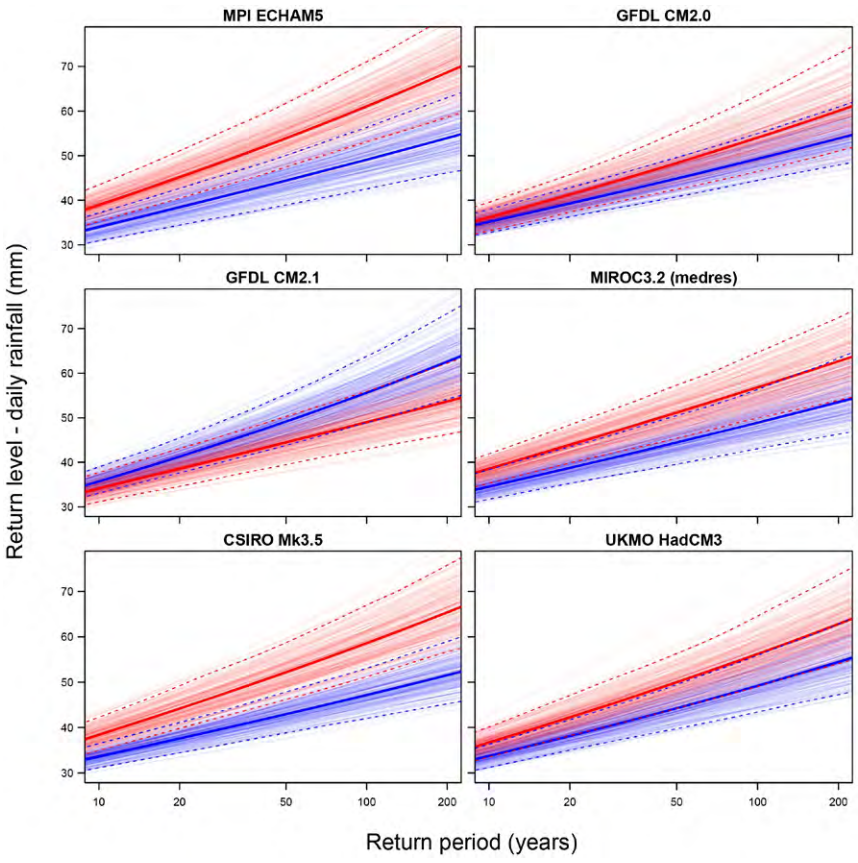


Figure 20. Analysis of projections of rainfall extremes from current (blue) and future (red) climates from global and regional climate models found that four out of the six models projected an increase of about 15 mm in the 100-year return level of annual maximum daily rainfall for Adelaide. This means that a one in a 100 year event may become a one in 30 year event.

Key climate research theme: Communication

Australia's decision makers and the general public are demanding greater insights into the drivers and likely impacts of climate change.

Clear and effective communication assists with, and encourages, collaboration. It also supports the uptake and application of the research findings by Government and other stakeholders.

The ACCSP provides material (such as climate projections, fact sheets, video clips and science information papers) to Commonwealth and State departments, local government, industry and to the general public.

The ACCSP also generates research cited by the IPCC, which positions Australia strongly in the international climate science community.

Table 9. In 2011-12, the ACCSP's *Communication and co–ordination* program managed Australia's key investment in climate science and helped inform the country's decision makers about the causes, nature, timing and consequences of climate change.

Research program area	Project title	Our targets	What was delivered
Communication and co–ordination	**7.1 ACCSP – Program management, coordination, and communication**	• Effective management of the ACCSP • Oversight of annual review and planning • Implementation of strategic communication plan	• Delivery and management of 27 climate science projects in 2011-12 • ACCSP Annual Report 2010-11 • ACCESS quarterly brief to government stakeholders • Contributions to *State of the Climate 2012* – an updated summary of Australia's long term climate trends • Contributions to Greenhouse gases website site (http://www.csiro.au/greenhouse-gases/) 34,707 hits since the site was launched on 1 June 2011 – 30 June 2012 • Inspiring Australia grant awarded for the development of a series of climate change animations • Planning and website for GREENHOUSE 2013 to be held in Adelaide, South Australia (www.greenhouse2013.com) • Collaboration with the broader science community (including universities and the ARC Centre of Excellence for Climate System Science) and supported international linkages including science contributions to the *IPCC Fifth Assessment Report* and planning for the IPCC Working Group 1 meeting

Communication highlights

Human activity affecting natural climate systems

The ACCSP communicated to a wide range of audiences, from policy makers and the media to the general public. The overarching message for all audiences was that human activity is having an impact on natural climate systems and that science is critical for understanding what the impacts mean now and in the future. ACCSP Manager Paul Holper said the science of climate change is a complex and a highly specialised field of study. Like any other area of science, it has its own unique language, technical terms, concepts, acronyms, and abbreviations that are not easily understood by people who are not experts in the field. It is therefore important to communicate clearly and effectively so that people without this expertise can more easily understand the changes scientists are seeing now and what we can expect to see in the future.

While communication to non-experts is a priority, communication between scientists is important so they can stay up to date, collaborate with others, and collectively contribute to the body of knowledge and evidence for climate change. The peer-reviewed publishing process ensures that formal communication of climate change science outcomes is objective, unbiased and conforms to accepted scientific standards.

Some key events where ACCSP scientists presented the outcomes of their work included:

- *Earth on the Edge: Science for a Sustainable Planet*, the 25th General Assembly of the International Union of Geodesy and Geophysics
- Annual ACCSP planning meeting in Melbourne in November 2011
- Annual ACCSP review meeting in Hobart in May 2012
- Regional Programs Workshop in Canberra on 29 May 2012
- Climate change communication community of practice workshop in Melbourne on 20 June 2012
- *National Climate Change Adaptation Research Facility* conference in Melbourne from 26-28 July 2012

Media releases that arose directly from ACCSP research or publicised relevant work can be found in Appendix 3 on page 43.

Website addresses with ACCSP information can be found in Appendix 4 on page 45.

A list of peer-reviewed papers can be found in Appendix 5 on page 46.

This is a highlight of project 7.1 in Table 9.

Appendix 1: Project list

Table 10. In 2011-12, the ACCSP delivered 27 projects across seven program areas:

Key climate research theme	Research program area	Project title	Research organisation
Greenhouse gases	**1. Global and regional carbon budgets**	1.1 The Australian continental carbon balance	CSIRO
		1.2 Global Carbon Project	CSIRO
		1.3 Land and ocean carbon feedbacks in the palaeo record	CSIRO
		1.4 Southern Ocean carbon dioxide sink	CSIRO
Atmosphere	**2. Land & air observations and processes**	2.1 Reducing uncertainties in climate projections by understanding, evaluating and comparing climate change feedbacks	BoM
		2.2 Aerosol and its impact on Australian climate	CSIRO
		2.3 Improving CABLE–SLI (CSIRO model that calculates carbon, water and heat exchanges between the land surface and atmosphere) with spatially-distributed biophysical and standing structural parameters for a forest ecosystem	CSIRO
Coasts & oceans	**3. Coasts & oceans**	3.1 Ocean climate processes: ocean monitoring to understand ocean control of the global and Australian climate	CSIRO
		3.2 Ocean climate processes: understanding ocean change and influence on global and Australian climate	CSIRO
		3.3 Ocean carbon and acidification	CSIRO
Water	**4. Modes of climate variability and change**	4.1 The Australian monsoon: processes, projections and extreme rainfall	BoM
		4.2 Detection and attribution of Australian climate change, rainfall and weather systems	BoM, CSIRO
		4.3 Near-term climate projections and predictions	CSIRO, BoM
		4.4 Understanding southern hemisphere climate projections using sensitivity experiments with the ACCESS model	BoM
		4.5 Global warming, El Niño-Southern Oscillation, the Walker circulation, and the Hadley circulation	BoM
		4.6 The response of the Indo-Pacific ocean variability to climate change and its impact on the Australian climate	CSIRO, BoM
An Australian climate modelling system	**5. Earth system modelling and data integration**	5.1 Development of the ACCESS coupled modelling system	BoM, CSIRO
		5.2 Evaluation of ACCESS simulations of reactive and long-lived gases and aerosol in the Australian region	CSIRO
Extremes	**6. Future climate predictions**	6.1 Improved sea-level, wind-wave and storm surge projections	CSIRO
		6.2 Regional climate projections science, including downscaling	CSIRO
		6.3 Climate extremes portal	CSIRO
		6.4 The influence of climate change on extreme events associated with East Coast Lows	BoM
		6.5 Trends and projected changes in cyclonic rainfall	CSIRO
		6.6 Application of the Bureau of Meteorology statistical downscaling model to Coupled Model Intercomparison Project 5 models	BoM
		6.7 Tropical cyclone database repair	BoM
		6.8 Projected changes in Australian rainfall extremes	CSIRO
Communication	**7. Co-ordination & communication**	7.1 ACCSP – Program management, coordination, and communication	CSIRO & BOM

Appendix 2:
Other partners

In 2011-12 the ACCSP collaborated with the following partners:

Universities

- Australian National University
- Charles Darwin University
- James Cook University
- Macquarie University
- Monash University
- Queensland University of Technology
- Southern Cross University
- Swinburne University
- University of Adelaide
- University of Melbourne
- University of New South Wales
- University of Queensland
- University of South Australia
- University of Sydney
- University of Tasmania – The Institute of Marine and Antarctic Studies
- University of Technology Sydney
- University of Western Australia
- University of Wollongong

National

- Antarctic Climate and Ecosystems Cooperative Research Centre
- Australia's Integrated Marine Observing System
- Australian Antarctic Division
- Australian Institute of Marine Science
- Australian Nuclear Science and Technology Organisation
- Integrated Marine Observing system
- National Computational Infrastructure
- Queensland Climate Change Centre of Excellence
- Royal Australian Navy
- The Goyder Institute

International

- Alfred Wegener Institute for Polar and Marine Research, Germany
- Atlantic Oceanographic and Meteorological Laboratory, National Oceanic and Atmospheric Administration, USA
- Centre for Ice and Climate, University of Copenhagen, Denmark
- Centre National de la Recherche Scientifique, Laboratoire de Glaciologie et Géophysique de l'Environnement, France
- College of Global Change and Earth Systems Modelling, Beijing Normal University, China
- Department of Earth and Environmental Sciences, University of Rochester, USA
- Department of Earth Sciences, Uppsala University, Sweden
- Departments of Earth & Planetary Science and of Chemistry, University of California, USA
- Disaster Prevention Research Institute, Kyoto University, Japan
- Duke University, USA
- Environment Canada, Toronto, Canada
- Escola Naval, CINAV, Lisbon, Portugal,
- Geophysical Fluid Dynamics Laboratory, Princeton, New Jersey, USA
- Institut de Recherche pour le Développement, Noumea, New Caledonia
- Institute for Marine and Atmospheric research Utrecht, Utrecht University, The Netherlands
- Institute of Arctic and Alpine Research, University of Colorado, Boulder, USA
- Institute of Atmospheric Physics, Chinese Academy of Sciences, China
- Institute of Oceanology, Chinese Academy of Sciences, China
- International Argo program (more than 15 countries – http://www.argo.ucsd.edu/)
- International Geosphere-Biosphere Programme, Stockholm, Sweden
- Japan Agency for Marine Science and Technology
- Japan Agency for Marine-Earth Science and Technology
- Laboratoire d'Océanographie et du Climat, France
- Laboratoire d'Océanographie et du Climat : Expérimentation et Approches Numériques, Institut Pierre Simon Laplace, France
- Lamont Doherty Earth Observatory, USA
- Low Temperature research laboratory, Japan
- MetOffice, Exeter, UK
- NASA Goddard Space Flight Center, USA
- National Center for Atmospheric Research, USA
- National Institute for Environmental Studies, Japan
- National Institute for Water and Atmosphere, New Zealand
- National Oceanic and Atmospheric Administration, USA
- National Oceanographic Data Centre, USA
- Oregon State University, USA
- Pacific Marine Environmental Laboratory, National Oceanic and Atmospheric Administration, USA
- Pacific Marine Environmental Laboratory, USA
- Princeton University, USA
- School of Earth and Environmental Sciences, Seoul National University, Republic of Korea
- The National Center for Atmospheric Research, USA
- Université Pierre et Marie Curie, France
- University of Exeter, Exeter, UK
- University of Hawaii, USA
- School of Environmental Sciences, University of East Anglia, United Kingdom

Appendix 3: Media releases

Table 11. The following media releases arose directly from ACCSP research or publicised relevant work.

Media release	Date distributed	Web link
Fewer rain storms across southern Australia Decreasing autumn and winter rainfall over southern Australia has been attributed to a 50-year decrease in the average intensity of storms in the region – a trend which is forecast to continue for another 50 years	4 Jul 2011	http://www.csiro.au/Organisation-Structure/Divisions/Marine--Atmospheric-Research/Fewer-rain-storms-across-southern-Australia.aspx
How the frequency and intensity of wildfires and intentional biomass burning will change in a future climate requires closer scientific attention, according to CSIRO's Dr Melita Keywood	5 Jul 2011	http://www.csiro.au/Portals/Media/Future-fire.aspx
The impacts on Australia of a 4ºC increase in average annual temperatures – including major reductions in annual rainfall in southern Australia, marked increases in evaporation nationwide and reduced snow cover in alpine regions – were presented today by CSIRO's Dr Penny Whetton at the Four Degrees climate change conference in Melbourne	12 Jul 2011	http://www.csiro.au/en/Portals/Media/Four-degrees-scenarios-for-Australia-future-climate.aspx
Australian scientists have sought the help of the United States and Australian navies to plug a critical gap in their Argo ocean and climate monitoring program caused by Somali pirates operating in the western Indian Ocean	14 Jul 2011	http://www.csiro.au/Portals/Media/Indian-Ocean-pirates-impede-climate-observations.aspx
One of Australia's leading climate change modelling experts, CSIRO Wealth from Oceans Flagship's Dr Wenju Cai, has been awarded a five-year CSIRO fellowship to establish a new research team examining climate influences on Australia	18 Jul 2011	http://www.csiro.au/en/Portals/Media/New-climate-change-research-team-established.aspx
Three deep-ocean moorings have become the foundation for a new drive to measure change in currents linking the Pacific and Indian Oceans through the Indonesia Archipelago – a key factor influencing Australia's climate	28 Jul 2011	http://www.csiro.au/Portals/Media/Deep-ocean-sentinels.aspx
A new insight into global photosynthesis, the chemical process governing how ocean and land plants absorb and release carbon dioxide, has been revealed in research that will assist scientists to more accurately assess future climate change	29 Sep 2011	http://www.csiro.au/Portals/Media/A-new-leaf-turns-in-carbon-science.aspx
An exciting new research Supersite will use a climate station to monitor Western Australia's 16 million hectare Great Western Woodland	3 Nov 2011	http://www.csiro.au/Portals/Media/Supersite-Woodlands-Climate.aspx
An international research team has balanced the sea-level rise budget by showing that the total amount of contributions to sea level rise explains the measured rise over recent decades	4 Nov 2011	http://www.csiro.au/en/Portals/Media/Auditing-the-Earths-sea-level-and-energy-budgets.aspx
Global carbon dioxide emissions increased by a record 5.9 per cent in 2010 following the dampening effect of the 2008-2009 Global Financial Crisis (GFC), according to scientists working with the Global Carbon Project	5 Dec 2011	http://www.csiro.au/en/Portals/Media/Global-Carbon-Project.aspx

Media release	Date distributed	Web link
In the future fewer tropical cyclones may form off Western Australia but they may become more intense, shows new research from a Western Australian climate research collaboration	5 Dec 2011	http://www.csiro.au/en/Portals/Multimedia/CSIROpod/Fewer-cyclone-hit-harder.aspx
Australia's land and oceans have continued to warm in response to rising CO_2 emissions from the burning of fossil fuels	13 Mar 2012	http://www.csiro.au/Portals/Media/State-of-the-Climate-2012.aspx Website visits: 3,746 (from 1 April 2012 – 30 June 2012)
Australian, Korean and US scientists have generated a 65-year record of southern hemisphere nitrous oxide measurements establishing a new benchmark against which to compare changes in the long-lived greenhouse gas that is also a major ozone-depleting substance	16 Mar 2012	http://www.csiro.au/Portals/Media/Growing-nitrous-oxide-levels.aspx
CSIRO oceanographers leave Brisbane this week on a 10-day, $2 million research voyage they believe will generate the most complete profile yet of one of Australia's most influential environmental features, the East Australian Current	18 Apr 2012	http://www.csiro.au/Portals/Media/East-Australian-Current-on-science-watch.aspx
A clear change in salinity has been detected in the world's oceans, signalling shifts and an acceleration in the global rainfall and evaporation cycle	26 Apr 2012	http://www.csiro.au/Portals/Media/Earths-water-cycle-intensifying-with-atmospheric-warming.aspx
New research by teams of Australian and US scientists has found there has been a massive reduction in the amount of Antarctic Bottom Water found off the coast of Antarctica	4 May 2012	http://www.csiro.au/en/Portals/Media/Deep-Ocean-Warming.aspx
Australia's leading climate change science conference – GREENHOUSE 2013 – will be held in Adelaide from 8-11 October 2013	19 Jun 2012	http://www.premier.sa.gov.au/images/news_releases/12_06Jun/greenhouse_2013.pdf

Appendix 4: Websites

Table 12. In 2011-12, the ACCSP communicated climate change science and related information to the wider community via the following web sites:

What	Organisation	Web address	Comments
About the ACCSP	DCCEE	www.climatechange.gov.au/en/government/initiatives/accsp.aspx	There is also general climate change information on this website
About the ACCSP	CSIRO	www.csiro.au/org/Australian-Climate-Change-Science-Program.html	There is also general climate change information on this website
Australian Climate Change Science	DCCEE	www.climatechange.gov.au/climate-change/national-framework-science.aspx	This page includes information about the ACCSP, the National Framework for Climate Change Science, and the Plan for Implementing Climate Change Science in Australia
Observed Australian climate trends	BOM	www.bom.gov.au/climate/change/	There is also general climate change information on this website
Australian national and state-wide climate projections	CSIRO, BOM, DCCEE	www.climatechangeinaustralia.gov.au/	The projections are freely available
Australian climate scenario generator	CSIRO	http://www.csiro.au/ozclim/home.do	The scenario generator is free to use, but you need to register
Greenhouse gas emission measurements	CSIRO	www.csiro.au/greenhouse-gases/	The latest greenhouse gas data updated monthly from one of the cleanest air sources in the world, Cape Grim, on Tasmania's west coast
Climate extremes portal	CSIRO, BOM, DCCEE	www.extremes.climatechangeinaustralia.gov.au	Expected to be available from late 2012 – provides free access to the latest research on temperature extremes, drought, flood, storms and tropical cyclones, fire weather, and coastal extremes

Appendix 5:
Peer-reviewed publications

In 2011-12, ACCSP researchers published 110 peer-reviewed papers or articles in Australian and international scientific publications. A further 13 were in press and 14 were submitted for publishing.

ACCSP scientific papers in journals and book chapters are peer reviewed to ensure that the published findings are objective, unbiased and conform to accepted scientific standards.

The following papers are sorted alphabetically under the key national climate change challenges.

Greenhouse gases

Ahn J, Brook E, Mitchell L, Rosen J, McConnell J, Taylor K, Etheridge D, and Rubino M. 2012. Atmospheric CO_2 over the last 1000 years: A high-resolution record from the West Antarctic Ice Sheet (WAIS) Divide ice core. *Global Biogeochemical Cycles* 26:11 p.

Andres RJ, Boden TA, Bréon FM, Ciais P, Davis S, Erickson D, Gregg JS, Jacobson A, Marland G, Miller J, Oda T, Olivier JGJ, Raupach MR, Rayner P, and Treanton K. 2012. A synthesis of carbon dioxide emissions from fossil-fuel combustion. *Biogeosciences* 9, 1845-1871 (doi:10.5194/bg-9-1845-2012).

Buizert C, Martinerie P, Petrenko V, Severinghaus J, Trudinger C, Witrant E, Rubino M, Etheridge D, and Steele LP, Hogan C, Laube JC, Sturges WT, Levchenko VA, Smith AM, Levin I, Conway TJ, Dlugokencky EJ, Lang PM, Kawamura K, Jenk TM, White JWC, Sowers T, Schwander J, and Blunier T. 2012. Gas transport in firn: multiple-tracer characterisation and model intercomparison for NEEM, Northern Greenland. *Atmospheric Chemistry and Physics* 12:4259-4277.

Canadell JG, Ciais P, Gurney K, Le Quéré C, Piao S, Raupach MR, and Sabine CL. 2011. An international effort to quantify regional carbon fluxes. *EOS Transactions* 92, 81-82.

Dahl-Jensen and NEEM Community Members. Eemian interglacial reconstructed from Greenland folded NEEM ice core strata. 2012. *Nature* (Submitted).

Friedlingstein P, Solomon S, Plattner GK, Knutti R, Ciais P, and Raupach MR. 2011. Long-term climate implications of 21st century options for CO_2 emission mitigation. *Nature Climate Change* 1, 457-461 (doi:10.1038/nclimate1302).

Haverd V, Lovell JL, Cuntz, M, Jupp, DLB, Newnham GJ, and Sea B. (2011) The canopy semi-analytic Pgap and radiative transfer (CanSPART) model – Part 1: formulation and application. *Agricultural and Forestry Meteorology* 158, Pg1-Pg12 (doi 10.1016/j.agrformet.2012.01.018).

Haverd V, Raupach MR, Briggs PR, Canadell JG, Davis SJ, Law RM, Meyer CP, Peters GP, Pickett-Heaps C, and Sherman B. 2012. The Australian Terrestrial Carbon Budget. *Biogeosciences Discussions 9, 12259–12308.*

Haverd V, Raupach MR, Briggs PR, Canadell JG, Isaac P, Pickett-Heaps C, Roxburgh SH, van Gorsel E, Viscarra Rossel RA, and Wang Z. 2012. Multiple observation types reduce uncertainty in Australia's terrestrial carbon and water cycles. *Biogeosciences Discussions 9, 12181–12258.*

Ignaciuk A, Rice M, Bogardi J, Canadell JG, Dhakal S, Ingram J, Leemans R, and Rosenberg M. 2012. Responding to Complex Societal Challenges: A Decade of Earth System Science Partnership (ESSP) Interdisciplinary Research. *Current Opinion in Environmental Sustainability* 4: 1-12 (DOI 10.1016/j.cosust.2011.12.003) www.sciencedirect.com/science/article/pii/S1877343511001370

Kilinc M, Beringer J, Hutley LB, Haverd V, and Tapper N. An analysis of the surface energy budget above the world's tallest angiosperm forest. *Agricultural and Forest Meteorology* (In press).

Lovell JL, Haverd V, Jupp DLB, and Newnham GJ. 2012. The canopy semi-analytic Pgap and radiative transfer (CanSPART) model: Validation using ground based lidar. *Agricultural and Forestry Meteorology* 160, Pg14-Pg35 (doi 10.1016/j.agrformet.2012.01.020).

Park S, Croteau P, Boering K, Etheridge D, Ferretti D, Fraser P, Kim K-R, Krummel P, Langenfelds R, van Ommen T, Steele P, and Trudinger C. 2012. Trends and seasonal cycles in the isotopic composition of nitrous oxide since 1940. *Nature Geoscience* 5:261-265.

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Appendix 6:
Other publications

In 2011-12, ACCSP researchers produced or contributed to 27 other publications including technical reports (many are peer-reviewed internally), conference papers and other publications.

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Contact details:

CSIRO Enquiries

1300 363 400
+61 3 9545 2176
enquiries@csiro.au
www.csiro.au

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Australian Government

Department of Climate Change and Energy Efficiency

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The Australian Climate Change Program undertakes research to improve our understanding of the causes, nature, timing and consequences of climate change for Australia and our region. The Program is administered by the Department of Climate Change and Energy Efficiency, with research undertaken by the Bureau of Meteorology and CSIRO.