Australian ClimateChange SciencePROGRAM

Annual Report 2010–2011

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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Australian Climate Change Science Program

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Australian Climate Change Science Program

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 2010-11, more than 100 climate scientists throughout Australia worked on more than 30 projects across seven program areas that addressed national climate priorities. As well as carrying out climate change research, the scientists presented their findings at workshops, conferences and many other local and international events. They published their findings in 147 peer-reviewed papers in Australian and international publications and 45 other publications for workshops, conferences, and other events.

The science undertaken by the ACCSP in the reporting year addressed the following themes: greenhouse gases, atmosphere, oceans and coasts, water, an Australian climate modelling system, extremes and communication. Outcomes of the science provided new, or supported existing, scientific evidence for human-induced climate change and improved our understanding of climate change.

As well as undertaking world-class research, communicating the outcomes of climate science is an important objective of the ACCSP. This annual report includes a list of peer-reviewed publications from research conducted under the auspices of the ACCSP, along with media releases, Australia's climate change websites and climate change video clips answering some commonly asked questions about climate change.

We would like to acknowledge the key people and organisations that have made it possible for the ACCSP to deliver world-class climate change science for Australia. We thank our scientists and other staff who are passionate about what they do and who are committed to improving our understanding of climate change and 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 to understand the impacts of climate change, develop ways to adapt and to manage its carbon emissions.

Mr Paul Holper

Manager,
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Dr Robert Colman

Climate Variability and Change Program,
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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 the key 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 in climate change.

Climate change science

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 2010-11, the ACCSP comprised 33 projects across the following program areas:

1. Global and regional carbon budgets
2. Land and air (observations and processes)
3. Oceans and coasts
4. Modes of climate variability and change
5. Earth system modelling and data integration
6. Predicting Australia's future climate and its extremes
7. Communication and co-ordination.

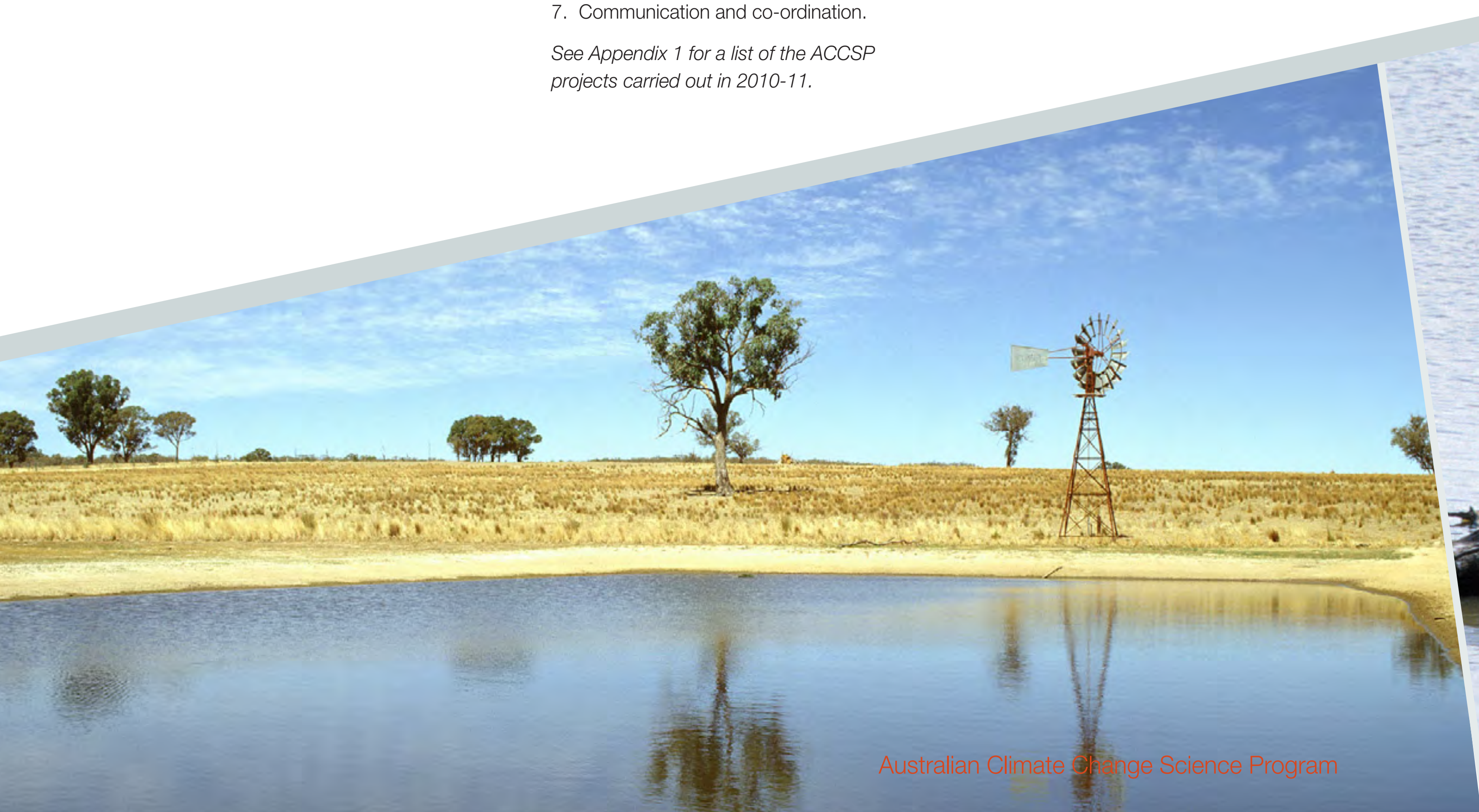
See Appendix 1 for a list of the ACCSP projects carried out in 2010-11.

Working together

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

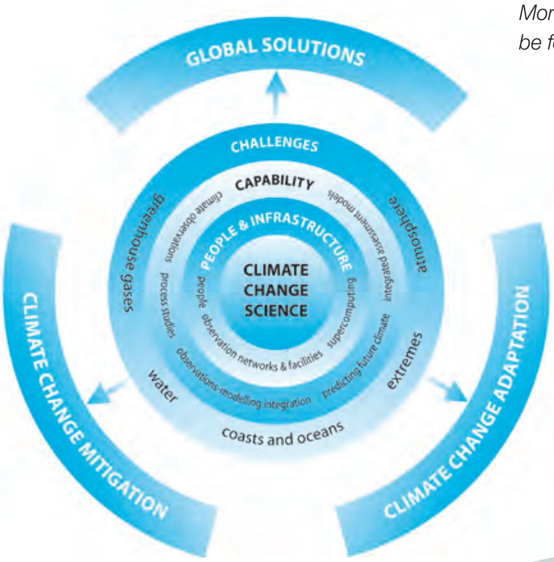
It does this mainly through the ACCSP, which is a partnership between the Department of Climate Change and Energy Efficiency (DCCEE), CSIRO and the Bureau of Meteorology (BoM).

With co-investment by CSIRO and BoM, the ACCSP represented investment of approximately $15m in 2010-11 in research directed to meet the shared goals and priorities of CSIRO, BoM, and DCCEE. These goals and priorities were advanced by the joint research program between CSIRO and BoM through the Centre for Australian Weather and Climate Research (CAWCR).



National climate science priorities

Projects conducted under the ACCSP in 2010-11 aligned with the Australian Government's priorities for climate system science. The Australian Government's National Framework for Climate Change Science (the Framework) describes national climate science priorities needed to address the climate change issues facing us over the coming decades. The Framework guides climate change research so that it can help Australia understand the impacts of climate change, develop ways to adapt and manage its carbon emissions.



The Framework comprises four main elements:

- challenges (what we need to understand and predict future climate changes)
- capabilities (what we need to maintain or develop to meet the challenges)
- people and infrastructure (what skills and infrastructure we need to support the capabilities); and
- implementation (national co-ordination and investment).

More information about The Framework can be found at www.climatechange.gov.au.

Figure 1. The Australian Government's National Framework for Climate Change Science is designed to address the climate change issues facing us over the coming decade.

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 high-quality peer-reviewed publications in national and international journals;
- Citation of our publications in the Assessment Reports produced by the Intergovernmental Panel on Climate Change (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.

Activities at a glance

Table 1. ACCSP activities in 2010-11

What	How many	Page
Key climate change challenges	7	31
Program areas	7	31
Projects	33	32
Other partners – national	12	33
Other partners – international	21	33
Peer-reviewed publications	147	35
Other publications	45	42
Media releases	24	29
Websites	7	30
Video clips	6	31

Science highlights at a glance

Table 2. In 2010-11, the ACCSP delivered outcomes that addressed the key national climate change challenges:

Key climate challenge	Research program area	Target outcomes	Highlights	Pages
Greenhouse gases	Global & regional carbon budgets Quantifying changes to the carbon cycle in the Australian region and globally	• A synthesis of the Australian terrestrial carbon balance • Monitoring of the evolution of multiple sources and sinks of carbon dioxide and the permissible emissions to achieve given temperature targets • Measurements of greenhouse gases and their tracer compounds back in time • Upgrading of the models of air movement and enclosure in the firn (compacted snow) and ice • Interpretation of the measured changes by developing the CSIRO climate and carbon models	• Carbon budget modelling has found that Australia's plant carbon uptake is highly variable • Revised and new data show a 20% decrease of net emissions from land use change • Measurements of ice cores from Law Dome in Antarctica show significant changes during the Little Ice Age cool period (about 1600 -1800 AD), implying that a small component (about 20 ppm) of the carbon dioxide increase over the past century was due to climate-carbon feedbacks	7-8
Atmosphere	Land and air observations and processes Improving our understanding and modelling of greenhouse gas flows between the land and the atmosphere	• Research programs at the new Australian tropical baseline station and integration with existing Australian greenhouse gas atmospheric observatory network • Continued measurements of carbon dioxide, water vapour and energy fluxes over a eucalyptus forest near Tumbarumba, NSW • Examination of natural aerosols over the Southern Ocean and Asian pollution aerosols • Quantification, understanding and evaluation of climate change feedbacks	• The pilot Australian tropical atmospheric observatory at Gunn Point, Northern Territory, will enable researchers to evaluate the impact of Australian tropical and temperate biomass burning on the cycling of greenhouse gases in the Australian region • Measurements of meteorology and the fluxes of carbon dioxide, water vapour and energy at a eucalyptus forest near Tumbarumba NSW have extended the data record to a decade • Preliminary research reveals that changes due to greenhouse gas emissions are likely to accelerate with the predicted reduction in aerosol pollution over the next few decades • Analysis suggests the differences in climate model feedbacks are directly responsible for around half the uncertainty in climate projections	9-10

Key climate challenge	Research program area	Target outcomes	Highlights	Pages
Oceans & coasts	Observing processes and developing projections	• Inversion modelling of the weakening of the Southern Ocean CO_2 sink • Understanding of the uptake of CO_2 and acidification of waters in the Australia region and Southern Ocean • Understanding of the processes driving the uptake of CO_2 in the Australia region and Southern Ocean and how they might alter under climate change • Ongoing development of the ocean climate observing system through partnership with Australia's Integrated Marine Observing System • Understanding of the role of the Southern Ocean in the climate system • Understanding of how and why global-averaged and regional sea level, ocean heat and salinity content are changing • Understanding of sea level change around the coast of Australia for improving regional projections	• The installation of a radon detector, with the Australian Nuclear Science and Technology Organisation, at Macquarie Island will establish the most accurate estimate of the magnitude of Southern Ocean carbon dioxide sink • Ocean research provided key data for assessing acidification change, the associated risk to ecosystems in our region, and for testing models used to predict ocean CO_2 uptake • Australia maintained the world's second largest array of Argo floats, co-chaired the Argo Project's International Steering Team, and audited the global ocean dataset to ensure climate accuracy and bias removal • An investigation of the Mertz Glacier tongue (which broke off after being hit by a 97 kilometre-long iceberg in 2010) enabled scientists to determine the sensitivity of bottom water formation to changes in greenhouse-gas-induced forcing, which will improve their modeling of this climate process • The book, *Understanding Sea-level Rise and Variability*, published in 2010-11, assesses knowledge and uncertainties about how and why the ocean is changing • Data from 14 observation platforms around the coast of Australia and continuous global positioning system measurements are determining the absolute sea level changes in a reference frame without platform or land movements contaminating the record	11-14
Water	Modes of climate variability and change Focusing on the hydrological cycle	• A more accurate and consistent record of tropical cyclone intensities and structures • A diagnostic process for assessing important extreme events • Analysis of the Australian monsoon using Coupled Model Intercomparison Project 3 (CMIP3) models in current and future simulations • Estimate of the impact of global warming on the Walker Circulation • Statistical analysis of methods used to examine likely future changes in El Niño/La Niña-Southern Oscillation • Understanding why the Indian Ocean Dipole may be more effective than El Niño-Southern Oscillation in generating temperature anomalies • Attribution of the causes of changing Australian climate • Assessment of how successful coupled climate models are at capturing modes of variability • Disentanglement of decadal variability from systematic changes due to anthropogenic forcing	• Improvements to the Australian tropical cyclone tracking database will help identify future trends in tropical cyclone frequency and intensity in Australia and throughout the world • Initial results from a large-scale diagnostic tool developed for identifying East Coast Lows in global climate model data indicate that there will be fewer in a warmer world • A better understanding of the processes behind the large uncertainty in changes to monsoon rainfall • Identification of both natural and human factors affecting the Walker Circulation • Research has discovered that the El Niño-Southern Oscillation influences southern Australia through the Indian Ocean by forcing large scale atmospheric waves ('Rossby waves') that have a centre south of Australia and lead to higher temperatures and lower rainfall in Southern Australia in winter and spring • Observations and climate model projections suggest that the ongoing downward trend in autumn and winter rainfall over mainland southern Australia is linked to reductions in the strength of the mid-latitude jet stream and the changing trend in atmospheric temperatures	15-18

Key climate challenge	Research program area	Target outcomes	Highlights	Pages
An Australian climate modelling system	Earth system modelling and data integration	• Coupled model testing and development • Preliminary evaluation of a global aerosol model	• Coupling of the ACCESS land surface model, CABLE, to ocean, sea ice and atmospheric component models. Previously, the only option was to use a less sophisticated land surface model in the coupled integrations • Improvements to the Australian Community Climate and Earth System Simulator (ACCESS) model has enabled it to now run efficiently on the National Computing Infrastructure and the Bureau of Meteorology computers • A preliminary evaluation of a global aerosol model's ability to reproduce regional and short-term variations in particle loadings suggests that the biomass burning emissions in 2007 and 2008 were underestimated for Northern Australia	19-20
Extremes	Future climate predictions	• Credible future regional climates and their likelihood • Methodology for future climate datasets that can be applied in impact and adaptation studies • Hydrodynamic modelling capability that enables direct downscaling of Coupled Model Intercomparison Project 5 (CMIP5) time-slice experiments for projected changes in storm surges • Understanding of weather events that are the predominant cause of coincident rainfall-storm surge and coastal erosion events along the Australian coastline • Improved projection of regional rainfall and temperature trends for the coming decades • A single multivariate (projecting multiple quantities, such as rainfall and temperatures) downscaling model • Understanding of Southern Hemisphere climate projections using sensitivity experiments with the ACCESS model • A method for using the eddy-resolving ocean carbon model of the Australian region to downscale climate change projections • Analysis of long-term observed wind speed over Australia • Delivery of climate projections through enhancements to the *OzClim* scenario generator and associated training • Development of statistical models for analysing extremes that may be dependent on other extremes, such as strong winds and fire	• Development of analysis methods for the upcoming CMIP5 climate model results (currently being generated) is preparing for the next round of national climate change projections • Contributions to co-ordinate international efforts in wave modelling • Analysis of tropical cyclone data from 1989 to 2009 shows there has been an increase in rainfall per tropical cyclone – particularly over northern Australia • Projections of climate scenarios from the CMIP 3 database are now available on a five km grid across Australia to assess rainfall and temperature changes • Researchers have increased the confidence in climate projections by understanding the physical mechanisms in the models that show variations in the strength of the Southern Annular Mode • Downscaling of CSIRO's climate change projections for the 2060s has shown that increasing the resolution leads to differences in climate change projections for surface warming and annual rainfall • *The Climate Change in Australia* and *OzClim* websites continued to attract many hits • Modelling simulations based on observed rainfall and storm surge data reveal the potential for larger flooding events than those experienced to date	21-26
Communication and co-ordination	Managing and co-ordinating the ACCSP Communicating the outcomes delivered by ACCSP	• Oversight of the ACCSP for BoM and CSIRO • Internal and external communication of the ACCSP findings	• A coordinated process for identifying research gaps, encouraging collaboration and assessing and selecting research proposals • Organisation and conduct of workshops for researchers and stakeholders • Contributions to a range of publications • Creation of science information papers, videos and web sites • Leading scientists from Australia and around the world presented the latest climate change developments to GREENHOUSE 2011 conference delegates	27-30

The year in review

Key climate challenge: Greenhouse gases

Climate change in the 20th century is largely being driven by increasing levels of atmospheric greenhouse gases generated by human activities.

The 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 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 2010-11, 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	Target outcomes	What was delivered
Global & regional carbon budgets	1.1 The Australian continental carbon balance	• A synthesis of the Australian terrestrial carbon balance including monthly time series (1990-2009) of ecosystem fluxes (gross primary productivity, net primary productivity, soil respiration) and stores (biomass, soil and litter carbon pools) and annual disturbance emissions (land-use change, fire)	• Estimates of the long-term mean carbon budget for the period 1990-2009 (excluding anthropogenic emissions) with the average (monthly) seasonal cycle • A breakdown and overview of the dominant underlying fluxes (and sub-regional hot-spots) including gross primary productivity, net primary productivity, heterotrophic respiration for each major of ecological region • Progress and preliminary results towards the inclusion of emissions from net flux disturbances (land use change plus fire) • A synthesis of top-down atmospheric inversions with bottom-up estimates to test the additional constraints gained from combining both approaches • Preliminary integration in CABLE of emissions from land use change and fire
	1.2 Global Carbon Project	• Monitoring of the evolution of multiple sources and sinks of carbon dioxide and the permissible emissions to achieve global temperature targets	• Investigation of carbon cycle processes likely to result in major feedbacks on global and Australian climates, using data and models • International collaboration and development of global assessments • Observed carbon cycle trends and their treatment in carbon climate models
	1.3 Land and ocean carbon feedbacks in the palaeo record	• Measurements back in time of the concentrations of the main atmospheric greenhouse gases and the ^{13}C isotope in CO_2 using air extracted from polar ice • Upgrading of the models of air movement and enclosure in the firn and ice to date the records and make corrections for diffusion • Development of the CSIRO Simple Carbon-Climate model for use in Global Integrated Assessment Modelling, ice core measurements and feedback analysis	• New measurements of CO_2, methane, and N_2O concentrations and isotopes of CO_2 and methane, centred on key climate variations of past centuries • Model simulations of the measurements described above, forced by proxy climate information and with isotope tagging • Estimated climate sensitivity of CO_2 and methane, with isotopic constraints on the main sources • Data provided to major research data bases and for IPCC and World Meteorological Organization assessments • Climate sensitivity and model developments reported at International Union of Geodesy and Geophysics conference in 2011 and article for *Atmospheric Chemistry and Physics* (in press) • Data provided to major research data bases and for IPCC and World Meteorological Organization assessments • Climate sensitivity and model developments reported at International Union of Geodesy and Geophysics conference in 2011 and article for Atmospheric Chemistry and Physics (in press) • Response to conclusions about methane sources in recent publication of *Science* • The CSIRO Simple Carbon-Climate model has been used in preliminary calculations to predict the response of the carbon cycle to reconstructions of global temperature. It complements the more complex models used in interpretation of ice core observations as it can quickly allow many calculations to be tested • The CSIRO Mk3L climate model has been coupled with a carbon cycle to assess our ability to simulate the climate of the Last Glacial Maximum

Science highlights

Australia's plant carbon uptake is highly variable

Australian plant growth (net primary productivity) leads to carbon uptake, but by an amount which is highly variable. The average variability from year to year of Australia's net primary productivity is larger than Australia's total greenhouse gas emissions from human activities. These findings were the results of a new estimate of the Australian biospheric carbon budget. CSIRO researcher Dr Vanessa Haverd achieved this through continental carbon and water cycle modelling. She produced simulations of monthly time series of carbon stored in plants, litter and soil, as well as fluxes of carbon between the biosphere and atmosphere at spatial resolution of about 5 km across the Australian continent. Another notable result from this work was that more than half of Australia's water lost through the transfer from land to the atmosphere does not pass through plants. This means that the transferred water does not participate in production of biomass.

This is a highlight of project 1.1 in Table 3.

Emissions from land use change fall by 20 per cent

Revised and new data show that changes to the way humans have used land have reduced net greenhouse gas emissions by 20 per cent – taking them down to 1.1 billion tonnes per year over the past five years. This is due to successful policies to slowdown deforestation, a decline in commodity prices, and wetter conditions in South-East Asia. While this is a positive sign, CSIRO researcher Dr Mike Raupach said that to remain under a peak global warming of 2°C above pre-industrial temperatures, humans need to keep total cumulative carbon emissions since pre-industrial times (1850) under 1000 billion tonnes. This would allow the burning of only about 500 billion tonnes of carbon in the future. To achieve this goal, total carbon emissions would need to peak at 12 billion tonnes (currently under 10 billion tonnes), which would lead to a peak atmospheric carbon dioxide concentration of 460 ppm. The economic downturn of 2009 resulted in a smaller than expected (1.3 per cent) reduction in global fossil fuel emissions. After compiling the global data, a larger increase than this is expected in 2010.

This is a highlight of project 1.2 in Table 3.

Looking at the past to look into the future

Future climate change will depend on how the sources and sinks of the main greenhouses gases behave in a warming world. Scientists expect that the ocean and terrestrial sinks of carbon dioxide, responsible for taking up about half of the greenhouse gas emissions from human activities, will weaken. This would cause a positive climate feedback, in which the warming from the increased levels of greenhouse gases would lead to higher concentrations of the gases in the atmosphere, further adding to the warming. Previous research also suggests that stores of methane, such as that locked up in permafrost, could be released. However, the uncertainty in these predictions is large.

CSIRO researcher Dr David Etheridge said that Australia's ice core collection from Law Dome, Antarctica, is enabling measurements of greenhouse gases and their trace compounds that identify their sources from thousands of years ago. The ice core collection is enabling CSIRO to focus on periods when natural variations were likely to have triggered a trace gas response. Dr Etheridge said that measurements show significant changes during the Little Ice Age cool period (about 1600 -1800 AD), implying that a small part (about 20 ppm) of the carbon dioxide increase over the past century was due to climate-carbon feedbacks. If the researchers can continue improving the models to simulate these events, then they will be able to better predict feedbacks.

This is a highlight of project 1.3 in Table 3.

Key climate **challenge:** Atmosphere

A key 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.

The critical issues that need addressing have been identified by the IPCC, the World Climate Research Programme, Global Climate Observing System, and the International Geosphere-Biosphere Programme. They include a better understanding of:

- cloud dynamics and convection, including their effects on radiative transfer
- cloud physics
- aerosol-cloud interaction
- atmospheric chemistry and the events that influence Australian climate, such as the El Niño - Southern Oscillation, the Sub-Tropical Ridge, the Southern Annular Mode, and stratospheric ozone depletion.

Table 4. In 2010-11, the ACCSP's *Land and air observations* program helped increase our knowledge and understanding of atmospheric behaviour.

Research program area	Project title	Target outcomes	What was delivered
Land and air (observations and processes)	2.1 Estimating Australian greenhouse gas sources from biomass burning	• Research programs at the new Australian tropical baseline station and integration with existing Australian greenhouse gas atmospheric observatory network	• A pilot Australian tropical atmospheric observatory at the Bureau of Meteorology Gunn Point site in the Northern Territory that continuously measured CO_2, 13 CO_2/12 CO_2 isotopic ratio, methane, meteorological parameters (wind speed and direction), and radon. Discrete flask air samples were also collected at the site and analysed by CSIRO's Marine and Atmospheric Research GASLAB for CO_2
	2.2 Using data from the Australian flux network (TERN/ OzFlux) and Tumbarumba flux station for ecosystem analysis and modelling	• Continued measurements of carbon dioxide, water vapour and energy fluxes over a eucalyptus forest near Tumbarumba, NSW	• Extension of the data record to 10 years • 11 scientific papers published in international refereed journals – through collaboration with Australian and international colleagues. Nine of these papers have used data from Tumbarumba
	2.3 ACCSP aerosol	• Examination of natural aerosols over the Southern Ocean and Asian pollution aerosols	• A scientific paper, *Simulated enhancement of El Niño/La Niña-Southern Oscillation-related rainfall variability due to Australian dust.* This is the first paper to demonstrate climatic effects due to the direct radiative effects of Australian dust • A large set of coupled atmosphere-ocean climate simulations
	2.4 Reducing uncertainty in climate sensitivity and climate projections	• Quantification, understanding and evaluation of climate change feedbacks (such as those due to water vapour, clouds, lapse rate and surface albedo)	• Calculations of feedbacks for inter-annual timescales for water vapour, surface albedo, temperature, and lapse rate • Moving, optimisation and testing of sophisticated feedback code (partial radiative perturbation) on the new National Computational Infrastructure supercomputer for analysing climate feedbacks in models • Paper in preparation on comparison of inter-annual and climate change timescale feedbacks • Extension of the feedback analysis under natural inter-annual to decadal variability (and ultimately to other timescales, including seasonal)

Science highlights

Tropical atmospheric observatory opens research doors

The pilot Australian tropical atmospheric observatory at Gunn Point could be used for an extensive range of research applications, such as estimating greenhouse gas emissions from biomass burning in the Australian tropics (savannah). CSIRO researcher Dr Marcel van der Schoot said the prevailing dry season meteorology exposes the site to air masses predominantly from northern Queensland and the Northern Territory. When combined with data from stations at Cape Grim (Tas), Cape Ferguson (Qld) and Otway (Vic), a comprehensive dataset of the cycling of the major greenhouse gases in the Australian region will be available for modelling studies. This will enable researchers to evaluate the impact of Australian tropical and temperate biomass burning on the cycling of greenhouse gases in our region. The observatory will expand its measurement program to include ozone, carbon monoxide and nitrogen oxide, radon, and short-lived halocarbons. The tropics play a major role in global climate through natural and anthropogenic processes, which have many potential feedbacks that are poorly understood. However, the tropics are the most sparsely sampled in global atmospheric observing networks.

This is a highlight of project 2.1 in Table 4.

Ongoing measuring extends data record

CSIRO researcher Dr Ray Leuning and his team have extended the data record by a decade through measuring meteorology and the fluxes of carbon dioxide, water vapour and energy at a eucalyptus forest near Tumbarumba in NSW. Tumbarumba is the flagship of 17 flux stations in the OzFlux network that provides nationally consistent, quality controlled datasets for a range of Australian ecosystems. OzFlux is part of a global network of about 500 flux stations. Dr Leuning said data from OzFlux and the global network are essential for estimating model parameters and for evaluating predictions of carbon, water and energy fluxes by the land surface scheme in the ACCESS model.

OzFlux is co-ordinated by CSIRO Marine and Atmospheric Research and is partially funded by the National Collaborative Research Infrastructure Strategy.

This is a highlight of project 2.2 in Table 4.

Human-produced aerosols mask greenhouse effects

The changes caused by greenhouse gas emissions are likely to accelerate with the predicted reduction in aerosol pollution over the next few decades. Research suggests that human-made aerosols may have substantially delayed greenhouse-induced changes in circulation and rainfall in Australia. CSIRO researcher Dr Leon Rotstayn said new simulations show that these aerosols delay the greenhouse-induced weakening of the Walker circulation, which is driven by increasing lower-atmospheric water vapour in a warmer climate. This means future climatic trends may look very different from trends over the past few decades. Further research will analyse these simulations in much more detail to evaluate the extent to which aerosols delay the effects of increasing greenhouse gases and whether they will lead to stronger trends in the Australian climate, including rainfall.

Aerosols are fine particles suspended in the atmosphere. Sources of human-produced aerosols include industry, motor vehicles and vegetation burning. Natural sources include volcanoes, dust storms and ocean plankton. Aerosols have long been known to exert a cooling effect on the climate.

This is a highlight of project 2.3 in Table 4.

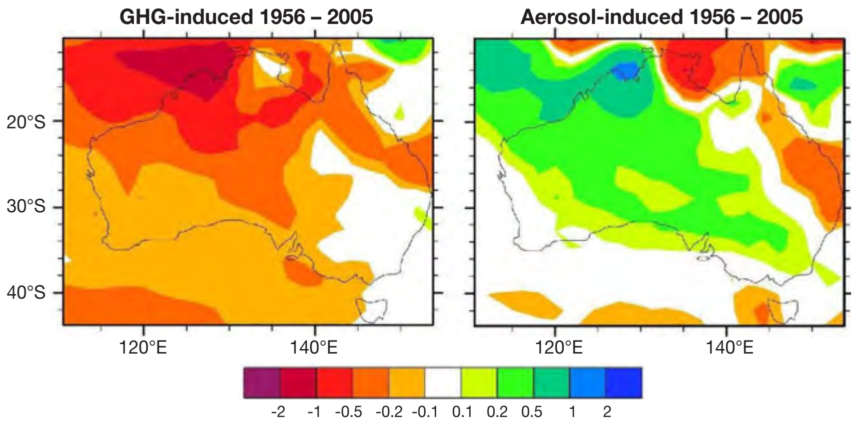


Figure 2. New simulations with the CSIRO-Mk3.6 climate model suggest that increasing greenhouse gases tend to cause a decrease of rainfall over much of Australia, whereas human-produced aerosols may have masked this effect. Simulated rainfall trends for the period 1956 to 2005 (in mm per day per century) are induced by increasing greenhouse gases (left panel) and by human-produced aerosols (right panel), and are substantially driven by changes in the Walker circulation. Future research will compare these results with other models from the IPCC Fifth Assessment Report, to assess the level of consensus among these new models, and the mechanisms that drive differing rainfall responses.

Reducing the uncertainty in climate projections

Differences in climate model feedbacks are directly responsible for around half the uncertainty in future climate projections. By understanding and evaluating how climate feedbacks vary in strength, researchers can understand and potentially reduce the source of much of the range of climate 'sensitivity' present in climate models. BoM researcher Dr Robert Colman found that inter-annual and other timescale feedbacks may provide tests of physical processes important for climate change. For example, changes in humidity or changes in snow or sea ice cover, amplify both variability on interannual timescales and temperature response to increases in CO_2 on decadal to centennial timescales. However, Dr Colman said the differences, particularly in the horizontal pattern of temperature changes, make simple conclusions difficult. Further investigation of the horizontal and vertical structure of feedbacks at decadal and seasonal timescales is needed. Investigation of the next generation of models (CMIP5) is also important. Dr Colman said it is important to understand and evaluate the vertical and horizontal structures of these feedbacks. This will help determine how closely they operate as analogues to climate change and how they can be most effectively used to evaluate climate model feedbacks.

This is a highlight of project 2.4 in Table 4.

Key climate challenge: Oceans and coasts

Sea level is rising, the oceans are warming and becoming more acidic and their 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 key 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 sea-level extreme 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;
- Sea surface temperature changes and the circulation of the Southern, Indian and Pacific Oceans, so we can understand their influence on rainfall patterns across southern Australia and identify the implications on our ecosystems as our coastal boundary currents change; and
- Ocean acidification for the marine biosphere, especially for coral reefs in our tropics and primary producers in the high latitudes of the Southern Ocean.

Table 5. In 2010-11, the ACCSP's *Oceans and coasts* program increased our knowledge and understanding of the current and likely changes in our oceans and coasts.

Research program area	Project title	Target outcomes	What was delivered
Oceans and coasts (observations, processes, projections)	3.1 Southern Ocean carbon dioxide sink	• Inversion modelling of the observed weakening of the strength of the Southern Ocean CO_2 sink	• Installation, with the Australian Nuclear Science and Technology Organisation, of a radon detector at Macquarie Island • Predictions of atmospheric CO_2 deviations from the baseline at Macquarie Island, with agreement being shown between model results and observed data
	3.2 Ocean carbon and acidification	• Understanding of the uptake of CO_2 and acidification of waters in the Australia region and Southern Ocean • Understanding of the processes driving the uptake of CO_2 and how they might alter under climate change	• Completion of Southern Ocean observations, modelling, and process studies from Antarctica to Hobart • Papers published and submitted on ocean uptake of CO_2 • Research including observations and modelling approaches aimed at developing Heron Island as an internationally significant site for acidification research • National meeting in Canberra: 'Ocean acidification: Implications for living marine resources in the Southern Hemisphere'
	3.3 Ocean climate data partnerships	• Ongoing development of the ocean climate observing system through partnership with Centre for Australian Weather and Climate Research and Australia's Integrated Marine Observing System	• Conference paper on continuing assessment of the use of offshore glider technology in the Tasman Sea, presented at GREENHOUSE 2011 in Cairns • Report on the design of East Australian Current monitoring using a mix of glider and moored technologies off Brisbane delivered to the CSIRO mooring team for action • Real-time regional and global ocean heat, freshwater content changes, sea level rise, and circulation changes data available on www.argo.net and www.imos.org.au • ~10,000 Australian ocean profiles delivered to international Argo data centres and the Integrated Marine Observing System (IMOS) portal – www.imos.org.au • Raw global Ship of Opportunity network data and ocean transport time-series to track major regional boundary current changes in the Tasman Sea delivered to IMOS; boundary current transports are yet to be completed, depending on the development of an international site for the global Ship of Opportunity network

Research program area	Project title	Target outcomes	What was delivered
Oceans and coasts (observations, processes, projections)	3.4 Ocean climate processes: understanding ocean control of global and Australian climate	• Understanding of the role of the Southern Ocean in the climate system	• Ocean observations and model simulations of the Southern Ocean, including topographically enhanced ocean mixing, ocean uptake of heat, carbon and chlorofluorocarbons, the impact of ocean warming on melting of the Antarctic ice sheet, and detection of change in the Southern Ocean and adjacent ocean basins • Global ocean patterns of thermosteric and halosteric (temperature and salinity induced) sea level change published • Documentation of how the ocean salinity field has changed and its relationship to warming rates in models and observations • Findings from major oceanographic expedition on the research icebreaker *Aurora Australis* to the Mertz Polynya region
	3.5 Global sea-level rise: reducing uncertainty and improving projections	• Understanding of how and why global-averaged and regional sea level, ocean heat and salinity content are changing for improving projections	• Near real-time sea-level time series and time series of ocean-heat content and steric sea-level: www.cmar.csiro.au/sealevel/ • *Absolute Calibration in Bass Strait, Australia: TOPEX, Jason-1 and OSTM/Jason-2* published in *Marine Geodesy* • Report on international consensus on eXpendable BathyThermograph (disposable instrument for measuring upper ocean temperature) fall rate correction to allow improved measurements of upper ocean temperature • *Understanding and projecting sea level change* published in *Oceanography*
	3.6 Australian baseline sea level monitoring array	• Understanding of sea level change around the coast of Australia for improving regional projections	• Maintenance and calibration visits to eight sea-level monitoring stations • Collection of continuous time series of sea-level data and related parameters from 14 observation platforms to ensure quality control and integrity of the time series • Maintenance of a database of observations for research and other use • Monthly data reports online at www.bom.gov.au/oceanography/projects/abslmp/reports.shtml • Updated sea level trends online at the monthly data reports link above and annual data report link below • Annual report 2009-10 online at http://www.bom.gov.au/oceanography/projects/abslmp/reports_yearly.shtml

Science highlights

Measuring the Southern Ocean carbon dioxide sink

The installation of a radon detector (which helps fingerprint the source of air samples), in collaboration with the Australian Nuclear Science and Technology Organisation, at Macquarie Island will help researchers enhance the interpretation of atmospheric carbon dioxide and oxygen/nitrogen ratios in the Southern Ocean. It will enable them to create the most comprehensive, precise and accurate dataset for carbon dioxide, carbon dioxide isotopes, and oxygen/nitrogen atmospheric mixing ratios. Future atmospheric modelling using this unique dataset, and collaboration with ocean modelling groups, will establish the most accurate estimate to date of the magnitude of the Southern Ocean carbon dioxide sink. CSIRO researcher Dr Marcel van der Schoot said the concentration data will be correlated with decadal changes in the long-term Southern Ocean carbon dioxide sink using past long-term datasets. He has started looking at differences between modelled and observed carbon dioxide deviations from the baseline data at Macquarie Island. Inverse modelling will begin when the final dataset is complete.

This is a highlight of project 3.1 in Table 5.

Monitoring ocean acidification and the risk to our ecosystems

The observations, modelling, and process studies of the Australia region and Southern Ocean are helping researchers understand how the ocean takes up carbon dioxide, the rate of acidification, and how the ocean will change in future. This Australian research is integrated with international efforts in other ocean basins. CSIRO researcher Dr Bronte Tilbrook said the ocean is the dominant long-term sink for carbon dioxide emissions, taking up about 25 per cent of the annual emissions resulting from human activity. The Southern Ocean and sub-polar waters act as one of the major sink regions on earth. While ocean uptake reduces the rate of atmospheric carbon dioxide increase, the carbon dioxide that dissolves in the seawater causes an increase in acidity levels. This is a serious threat to the health of Australia's marine ecosystems. However, the research indicates that some species of deep-sea coral are likely to be more resilient to acidification change than previously believed.

This is a highlight of project 3.2 in Table 5.

Australia has prominent role in Argo float project

Australia's role in the global Argo float project continues to increase – Australia now maintains the world's second largest array of floats, co-chairs the international Steering Team, and audits the global dataset routinely to ensure climate accuracy and bias removal. CSIRO researcher Dr Susan Wijffels said Australia's collection of Argo floats is growing due to the strong engineering performance of its floats, which have a life span of more than seven years. Australia has also been successful in piloting Iridium floats in the seasonal sea-ice zone, a 'blind spot' in the climate observing system. Dr Wijffels plans to begin working internationally on scoping an extension of the Argo floats into this zone. Looking ahead, Dr Wijffels said her team will improve the data return from our Argo floats by using Iridium communications. The team will also improve data streams delivered by deep water gliders off the east coast of Tasmania. It will implement a series of fixed instruments on deep sea tall moorings to monitor the East Australian Current in conjunction with the Integrated Marine Observing System deep moorings facility.

The Argo project is a collaborative effort involving about 50 research and operational agencies from 31 countries. There are approximately 3000 Argo floats in oceans around the world.

This is a highlight of project 3.3 in Table 5.

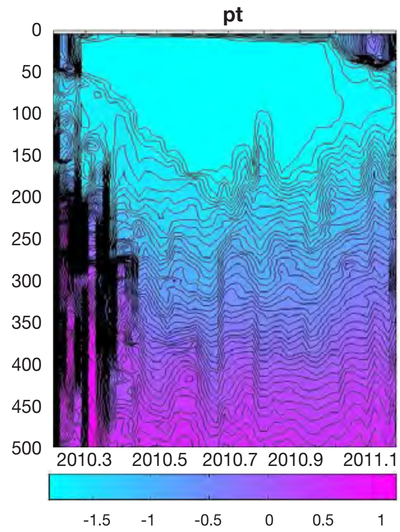


Figure 4. Deploying Argo floats in the seasonal ice zone is proving successful. This float delivered a rare record of the evolution of properties (including temperature) under the winter ice. A homogeneous and deepening pool of near freezing winter water builds up under the ice (becoming progressively saltier due to salt rejection from sea ice). When the ice retreats and melts with summer warming, a very fresh warm shallow surface layer is formed.

Figure 3. Argo floats are battery-powered autonomous devices that drift in the sea collecting high-quality temperature and salinity profiles from the upper 2000 metres of the ice-free global ocean. The ocean data are transmitted via satellite to scientists on shore.

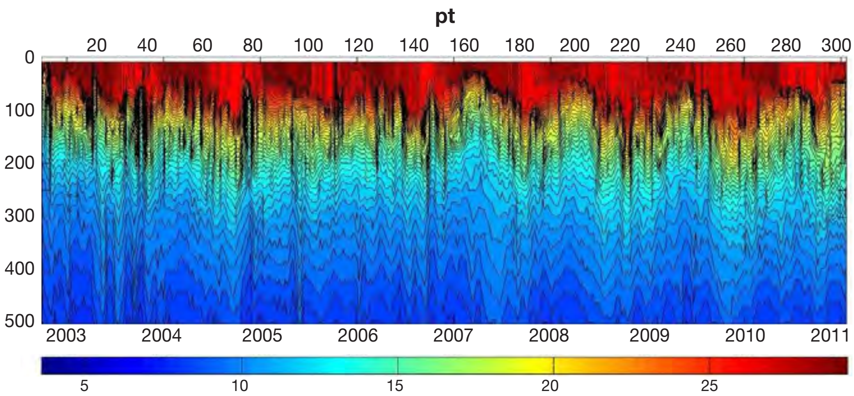


Figure 5. Upper ocean temperature as a function of depth and time from an Argo Australia float operating in the South Indian Ocean. This float is entering its ninth summer of autonomous and seamless data delivery from a platform initially believed to last only 3-4 years.

Calving of glacier gives latest information

One highlight from research helping to detect and interpret changes in Australia's oceans was a month-long oceanographic expedition on the research icebreaker *Aurora Australis* to the Mertz Polynya region. About 40 Australian and international scientists went on this major expedition to investigate 78 kilometres of the Mertz Glacier tongue, which broke off after being hit by a 97 kilometre-long iceberg in January 2010. CSIRO researcher Dr Steve Rintoul said the Mertz Polynya region is important because it is one of the few places in the ocean where dense, salty water forms at the surface and sinks four or five kilometres to the sea floor. This sinking of dense water near Antarctica is a key link in a network of ocean currents that influences global climate patterns. Dr Rintoul said the calving resulted in a 'natural' experiment, which allowed scientists to investigate the sensitivity of bottom water formation to changes in forcing. After the glacier tongue calved, the salinity and density of water on the shelf were dramatically reduced. This information will help improve modelling of this key climate process.

This is a highlight of project 3.4 in Table 5.

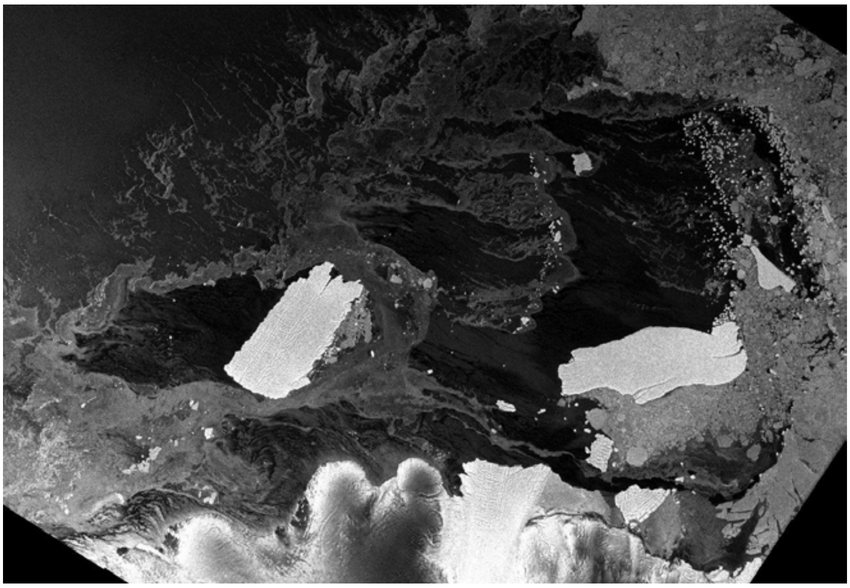


Figure 6. A satellite image of the Mertz Glacier region on 20 March 2010. The large iceberg on the right (97km long) collided with the Mertz Glacier Tongue and broke it off to form the new large iceberg on the left. This process results in the formation of large volumes of dense water. The dark areas on the figure are polynyas, areas of open water where new ice forms rapidly.

Improving long-term sea-level change estimates

Scientists are improving their estimates of long-term sea-level changes by closely observing the data from 14 observation platforms around the coast of Australia. By repeatedly and precisely levelling the sea-level gauges, they have found that the platforms holding the gauges move vertically and substantially at some sites. National Tidal Centre Manager Mr Bill Mitchell said the past platform movements would have affected sea-level records at the historical tide-gauge sites. To overcome this problem, the Australian Baseline Sea Level Monitoring project will continue to be operated and maintained in conjunction with continuous global positioning system measurements. Researchers need to monitor the land movement using the global positioning system over a sufficient length of time (approximately 10 years) before the measurements can be considered accurate enough. In this time, the researchers will be able to determine the absolute sea level change in a reference frame without the platform or land movements affecting the record.

This is a highlight of project 3.6 in Table 5.

Understanding why and how the ocean is changing

Understanding how and why the ocean is changing are critical for improving projections. Many observations show that the ocean has been changing over the past several decades. A key change is that the ocean is getting warmer and is increasing in volume through thermal expansion. The volume is also changing through more water being added from melting glaciers and ice sheets, and through changes in water storage on or in the land, for example from dams and extraction of water from aquifers. CSIRO researcher Dr John Church has published improved and updated estimates of sea-level rise using satellite and in situ observations. These are now freely available online (http://www.cmar.csiro.au/sealevel/). His book, *Understanding Sea-level Rise and Variability*, published in 2010-11 assesses current knowledge and uncertainties. An estimate of the total regional sea-level rise from the IPCC *Fourth Assessment Report* was also published. For the global average, observed sea level is close to the upper end of the panel's projections.

This is a highlight of project 3.5 in Table 5.

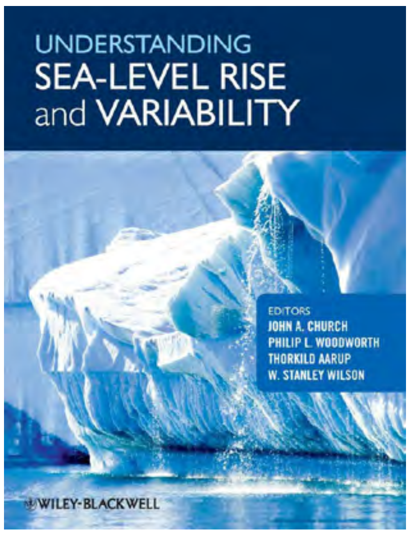


Figure 7: *Understanding Sea-level Rise and Variability* assesses knowledge and uncertainties about why and how the ocean is changing.

Key climate challenge: Water

Australia is the driest inhabited continent even though some areas have annual rainfall of over 1200 millimetres. 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.

Our demand for water is growing due to expanding urban areas, agriculture, and increasing demand for energy.

Recent dramatic reductions in rainfall and increased temperatures have led to an even greater reduction in run off over southern Australia. This has had significant impacts on the south-west of Western Australia, northern and eastern Tasmania, the south-east and eastern continental seaboard, and the Murray-Darling Basin. Research indicates that long periods of diminished rainfall and increased evaporation may become more frequent as a result of climate change.

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

To address these challenges, Australian science is needed to provide better information about likely future climate to help manage increasing demand for water.

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:

- 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;
- The influence of land-cover change on local and regional patterns of rainfall and evaporation; and
- Palaeo-hydrological research to clarify the long-term patterns of natural variability of the hydrological cycle to help assess the role of anthropogenic climate change on the observed rainfall and water availability trends in Australia over the past century and into the future.

Table 6. In 2010-11, 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	Target outcomes	What was delivered
Modes of climate variability and change	4.1 Tropical cyclone database review and repair	• A more accurate and consistent record of tropical cyclone intensities and structures for better assessing cyclone frequency and intensity trends	• Commencement of the cyclone tracking database (DVORAK) analysis, data recovery, verification, and correction for all Australian cyclones in the satellite era (Southern Hemisphere 90E–160E 1970 to present) • Development and testing of software that provides more accurate estimates of the core structure of a cyclone such as maximum wind speed and the atmospheric pressure pattern
	4.2 Impact of climate change on the risk of formation of East Coast Lows	• Analysis of the influence of climate change on East Coast Lows and associated extreme rainfall, wind and wave events	• Evaluation of global climate models' ability to provide a realistic climatology for East Coast Low formation • Modelled climatologies of current and future risk of East Coast Lows formation for CMIP3 models • Enhancement of the existing observed East Coast Lows database using surface-based observations (rainfall, wind) • *Large-scale diagnostics of extratropical cyclogenesis and associated extreme weather events in eastern Australia* submitted to the *International Journal of Climatology.* This paper is based on the *CAWCR Technical Report 37* published at www.cawcr.gov.au/publications/technicalreports/CTR_037.pdf
	4.3 The Australian monsoon: Processes, projections and extreme rainfall	• Analysis of the Australian monsoon using CMIP 3 models in current and future simulations	• Description of the strength of tropical convective processes simulated within global climate models and their importance for rainfall within the Australian monsoon system • Engagement with the National Computing Infrastructure facility in Canberra to gain access to the Earth System Grid (ESG) of CMIP5 simulations. Model data submission to the ESG was delayed due to global technical difficulties • Initial comparison of projections of Australian rainfall from dynamically downscaled simulations with those from their host global climate model

Research program area	Project title	Target outcomes	What was delivered
Modes of climate variability and change	4.4 Global warming, the Walker Circulation and *El Niño* - Southern Oscillation	• Estimate of the impact of global warming on the Walker Circulation (WC) • Statistical analysis of methods used to examine likely future changes in *El Niño* - Southern Oscillation	• Examined changes in the strength of the WC in both the observations and in WCRP/CMIP3 climate model simulations for the 20th and 21st centuries • External forcing and internally generated variability contributed to the observed weakening of the WC over the 20th century • External forcing accounts for approximately 50% +/- 20% of the observed weakening, with internally generated climate variability making up the rest. • The impact of global warming on the SOI was quantified for the first time, for both the 20th and 21st centuries, for the period June-December • *What caused the observed 20th century weakening of the Walker Circulation?* published in the *Journal of Climate* • *The impact of global warming on the tropical Pacific Ocean and El Niño* published in *Nature Geoscience*
	4.5 The response of Indo–Pacific ocean variability to climate change and its impact on Australian climate	• Understanding of why the Indian Ocean Dipole may be more effective than the *El Niño*-Southern Oscillation in generating temperature anomalies over north-west Australia	• *Interactions of ENSO, the IOD, and the SAM in CMIP3 models* published in *Journal of Climate* • *Simulation of the Indian Ocean Dipole: A relevant criterion for selecting models for climate projections* published in *Geophysical Research Letters* • *Influence of global-scale variability on the subtropical ridge over southeast Australia being* published in *Journal of Climate* • *Teleconnection pathways ENSO and the IOD and the mechanisms for impacts on Australian rainfall* being published *in Journal of Climate* • *The impact of Asian and non-Asian aerosols on 20th century Asian summer monsoon* published in *Geophysical Research Letters* • *Are anthropogenic aerosols responsible for the northwest Australia summer rainfall increase? A CMIP3 perspective and implications* published in *Journal of Climate*
	4.6 Attribution and projection of Australian climate, rainfall and large scale modes	• Attribution of the causes of changing Australian climate • Assessment of how successful coupled climate models are at capturing the changes • Disentangling of decadal variability from systematic changes due to anthropogenic forcing	• Documentation of changes in the southern hemisphere circulation, Australian climate and rainfall during the 20th century • Assessment of the CMIP3 coupled ocean atmosphere models for their ability to reproduce the changed circulation, climate, rainfall and modes of variability during the 20th century • Understanding of the relative contributions of inter-annual to inter-decadal variability and systematic anthropogenic forcing in the observed changes in the 20th century • Inverse modelling methods were used to attribute forcings associated with changes in the Southern Hemisphere climate

Science highlights

Updated tropical cyclone database

The Australian tropical cyclone tracking database uses 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. Because the science and techniques have evolved since this technique was developed, there are now biases in the data that are likely to show false or misleading trends. In recent years, scientists have been able to evaluate the quality of the satellite data, make repairs to gross errors and omissions in the existing database, and refine the science for determining tropical cyclone intensity using the DVORAK satellite analysis technique. This has enabled them to begin reviewing past analyses using current knowledge and techniques. Dr Hakeem Shaik from BoM said work has begun on DVORAK analysis data recovery, verification, and correction for all Australian tropical cyclones in the satellite era. The Vortex specification software has also been updated to include additional structural parameters: maximum wind, radius of maximum wind, radius of 34-knot winds, and radius of last closed isobar. This improved database will help scientists to identify possible future trends in tropical cyclone frequency and intensity in Australia and throughout the world.

This is a highlight of project 4.1 in Table 6.

Fewer East Coast Lows in a warmer world

A large-scale diagnostic tool for identifying East Coast Lows in global climate model data suggests a reduction in the 21st century compared with the 20th century. BoM researcher Dr Andrew Dowdy said the initial results indicate that there will be fewer East Coast Lows in a warmer world. However, in future we may still experience very intense East Coast Lows. A number of large-scale diagnostics provided a good indication of East Coast Lows occurrence, as well as associated extreme rain events. Of those tested, a diagnostic tool based on geostrophic vorticity consistently produced the best results. There is also some indication that lows on the east coast are special because the diagnostic produces higher values here than for the surrounding region.

The diagnostic tool is based on a dataset of East Coast Lows developed by the NSW Regional Office of the Bureau of Meteorology. Although this dataset includes some information about associated extreme rainfall, it does not quantitatively grade the intensity of an East Coast Low. In 2012, the researchers will analyse extreme weather events associated with East Coast Lows to create a climatology with the most severe weather impacts. This climatology will then be used to refine the diagnostic tool so the researchers can examine the influence of climate change on the most intense East Coast Lows.

East Coast Lows are responsible for many of the most significant extreme weather events (in terms of damage) in Australia. They predominantly affect coastal eastern Australia, including the most populated areas of the country and provide a large proportion of the major inflows to urban water storages on the Eastern Seaboard. East Coast Lows are not well represented in coarse-resolution climate models and this project aims to address this issue.

This is a highlight of project 4.2 in Table 6.

Reducing the uncertainty of tropical rainfall simulations

Scientists have examined the processes behind the uncertainties in climate change rainfall simulations across tropical Australia. They found that a strong indicator for this uncertainty was the strength of the upward movement of heat and moisture associated with different intensities of convection in monsoon rainfall. BoM researcher Dr Aurel Moise said the analysis enabled the separation of future rainfall changes into two components. The first component is rainfall associated with more moisture in the atmosphere due to higher temperatures. The second component is rainfall associated with changes in large-scale circulation. Dr Moise said this analysis explains why there is such a large uncertainty in rainfall projections over tropical Australia with an overall non-significant change. The two components of rainfall changes are opposing each other. Increasing rainfall associated with changes in the moisture in the atmosphere is competing with decreasing rainfall associated with circulation changes. Now that the scientists understand what is causing the uncertainty, they can assess tropical rainfall models. They can then exclude those models that are unable to simulate the degree of upward motion of heat and moisture associated with monsoon rainfall. This will decrease uncertainty associated with tropical rainfall simulations.

The Australian Monsoon system provides most of the rainfall across the top end of Australia. Changes in the timing, positioning and intensity of the rainfall systems associated with the monsoon due to climate change would strongly affect many ecosystems, communities and sectors of the Australian economy.

This is a highlight of project 4.3 in Table 6.

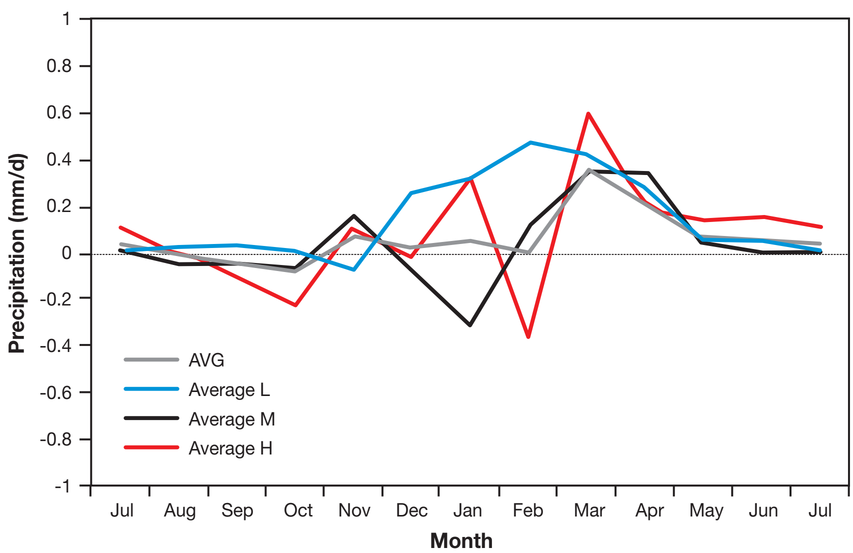


Figure 8. Changes in the seasonal cycle of rainfall across tropical Australia under a high emission scenario with models separated into low (blue), high (pink) and medium (black) convective strength. The ensemble mean model is shown in grey. The results show little consensus of the models on rainfall changes, except for late in the wet season (March - April), where they show a modest increase.

Natural and human factors affect Walker Circulation

The Walker Circulation is one of the world's largest and most important wind systems, involving the large scale circulation of air between the Australian region and the central and eastern Pacific ocean. 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 time in recorded history.

Research examining changes to the Walker Circulation found that it weakens in nearly all models during the 21st century. However, the Walker Circulation only weakens with a small majority of models during the 20th century. BoM researcher Dr Scott Power said the weakening shown in the models is much less than actually observed. The models best able to simulate El Niño-Southern Oscillation-related variability in the 20th century tended to show more pronounced weakening compared with the less skillful models. The analysis indicated that natural, internally-generated climate variability caused approximately half of the observed 20th century weakening in the Walker circulation, with the remainder caused by a combination of human activities, volcanoes and insolation (solar radiation energy) changes. This work provides the most reliable estimate to date of the relative importance of external factors on the observed decline in the strength of the Walker circulation.

This is a highlight of project 4.4 in Table 6.

Understanding the major drivers of climate variability

Scientists have shown that the Indian Ocean Dipole influences south-east Australia's climate during winter and spring. When the tropical eastern Indian Ocean is cooler than normal and the west is warmer, it corresponds to a positive phase of the Indian Ocean Dipole. The pattern induces a large wave structure in the atmosphere called a Rossby wave train, which has a high pressure centre south of Australia. This leads to higher temperatures and lower rainfall across southern Australia in winter and spring. It also affects the subtropical ridge over southeast Australia in these seasons.

CSIRO researcher Dr Wenju Cai said another important advance is the discovery of how the El Niño-Southern Oscillation affects southern Australia. When an El Niño occurs, southern Australia tends to be drier than normal. The research has shown that the El Niño-Southern Oscillation's influence on southern Australia is conducted through the Indian Ocean by forcing the Rossby wave train in the Indian Ocean. Previously, the process whereby an El Niño causes the drier conditions has not been well understood. It has also been complicated by the fact that an El Niño event often occurs in conjunction with a positive Indian Ocean Dipole event.

Dr Cai and his team also investigated whether the increase in human-generated aerosols has led to increasing north-west Australia summer rainfall over the past five decades. He said there is no consensus among climate models from the IPCC 4AR for an aerosol-induced increase. However, aerosols, particularly those from non-Asian sources, played an important part in the 20th century reduction of the Asian summer monsoon.

The Indian Ocean Dipole, El Niño-Southern Oscillation, and the Southern Annular Mode are major drivers of climate variability over Australia. They contribute to favourable conditions for major bushfires, droughts and floods. However, the processes in which these drivers influence our climate are not fully understood. This knowledge is fundamental for understanding their impact, and assessing how they will respond to human-generated aerosols and increasing atmospheric greenhouse gas concentrations. It is also crucial for selecting models for climate projections.

This is a highlight of project 4.5 in Table 6.

Explaining changes in long-term rainfall

The downward trend in autumn and winter rainfall over mainland southern Australia has been linked to reductions in the strength of the mid-latitude jet stream and the reduction in the temperature gradient between the subtropics and the higher latitudes. BoM researcher Dr Carsten Frederiksen said that these effects are hemispheric in scale and have resulted in a large decline in the intensity of storm formations over the last three decades compared with the previous three decades. The observations and climate models projections suggest these trends will continue over the next 50 years with increasing greenhouse gas concentrations. They also show that the impact of further greenhouse gas increases could lead to further large reductions in wind shear instability and storm formation during the 21st century, similar to those observed during the second half of the 20th century.

Dr Frederiksen and his team have also shown that rainfall increases over the North West of Western Australia and central Australia are caused by the surge of weather systems associated with north-west cloud bands and intraseasonal oscillations, which are tropical disturbances that switch 'on and off' the monsoons. They have also linked decreases in rainfall on the eastern seaboard during the last decade or so to a reduction in mid-latitude blocking, which is associated with the reduced development of rainfall events associated with East Coast Lows.

This is a highlight of project 4.6 in Table 6.

Key climate challenge: An Australian climate modelling system

Climate models are an important tool for understanding past and future changes in climate.

Climate models have become increasingly sophisticated. Earth system models now include atmosphere, ocean, land surface, sea-ice, aerosols, carbon cycle, and atmospheric chemistry so they can more realistically replicate the Earth's systems and feedbacks.

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

Global climate models typically have grid-points spaced 100 to 400 km 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 local scales giving better representation of regional processes such as weather and coastal and mountain effects. Both modelling approaches have strengths and weaknesses that need to be considered when developing climate projections and confidence levels.

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 Change and Earth-System Simulator (ACCESS). ACCESS will deliver a new generation of numerical models to improve weather and climate research in Australia.

Table 7. In 2010-11, ACCSP researchers continued to improve the capability of ACCESS component models and integration of additional models into the system.

Research program area	Project title	Target outcomes	What was delivered
5. Earth system modelling and data integration	5.1 Development of the ACCESS coupled modelling system	• Coupled model testing and development	• 'Core' long-term CMIP5 simulations and processed model output data on the National Computing Infrastructure Earth Systems Grid node • Set of skill score metrics targeted for objective evaluation of climate models, with a set of tools to calculate them and a database to support them • Development of the ACCESS atmospheric component • Calibration of CABLE/CASACNP* to ensure that the model can produce the observed surface fluxes of energy, water and carbon under different conditions for different vegetation types • Ensure that when running ACCESS with CABLE+CASACNP globally, the model can reproduce the current climate and observed surface CO_2 concentrations at different locations • State-of-the-art global land surface model of fully coupled energy, water, carbon and nutrient cycles • Simulation of the ocean and sea-ice component of ACCESS for the 1949-2009 period • Assessment of the climate-chemistry capability of ACCESS with a view to future Earth systems modelling • Continued optimisation of model code and development of the model infrastructure (e.g., user interfaces, pre- and post-processing of data)
	5.2 Evaluation of ACCESS simulations of reactive and long-lived gases and aerosol in the Australian region	• Preliminary evaluation of the ability of a global aerosol model to reproduce regional and short-term variations in particle loadings	• Database of aerosol, reactive gases and greenhouse gas observations • Compilation and analysis of a data set on aerosol composition at Charles Point in the Northern Territory and a draft paper • Upscaling of one dataset (aerosol optical depth) from observational spatial scales to ACCESS output scale • Review of methodologies used to compare observations with models • Report and critical review of observational data sets of aerosols, reactive gases and greenhouse gases and their suitability for comparison methodologies

Science highlights

Major progress with coupled modelling

A notable achievement this past year has been the coupling of the ACCESS land surface model, CABLE, to ocean, sea ice and atmospheric component models. Previously, the only option was to use a less sophisticated land surface model in the coupled integrations. CSIRO researcher Dr Tony Hirst said that the ocean and sea-ice model codes were also upgraded, which has improved model parametrisations and model output options. New land-sea 'masks' were introduced to improve the treatment of coastal features and an extensive review of the model code rectified a range of inadequacies. The ACCESS coupled model now runs more efficiently on the National Computing Infrastructure (NCI) and the Bureau of Meteorology machines. A help desk has been established at NCI to support users of the ACCESS atmospheric model. Universities associated with the Centre of Excellence for Climate System Science will be providing significant additional resources to support ACCESS development and testing.

ACCESS represents the next generation of climate system modelling being developed in Australia.

This is a highlight of project 5.1 in Table 7.

Biomass burning emissions underestimated

A preliminary evaluation of the ability of global aerosol models to reproduce regional and short-term variations in particle loadings suggests that the biomass burning emissions in 2007 and 2008 were underestimated for Northern Australia. CSIRO researcher Dr Melita Keywood said smoke from biomass burning is a significant source of atmospheric aerosol in tropical Australia during the dry season. However, dust is the major source of atmospheric aerosol in central Australia. The global aerosol model also suggested that the dust formation module may need further refining for Australian conditions. It is important to better understand aerosol effects to resolve modelled and observed climate variability and climate change.

Global climate models are important tools for understanding the influence of aerosols and multiphase atmospheric chemistry on climate.

This is a highlight of project 5.2 in Table 7.

Key climate **challenge:** Extremes

Extreme weather events are rare and often damaging. They can include severe temperatures, torrential rainfall, large hail, strong wind gusts, bushfires, tropical cyclones, and high sea level events.

In Australia the impact and cost of recent extreme events have been significant:

- The Victorian bushfires in early February 2009 killed 173 people and more than a million animals. They destroyed more than 2000 homes, burnt about 430,000 hectares, and cost about $4.4 billion (Victorian Bushfires Royal Commission)
- The south–east Australian heat wave in late January 2009 resulted in 374 more deaths in Victoria than would be normally expected (Victorian Department of Human Services)
- The hailstorm in Sydney on 14 April 1999 resulted in insurance claims totalling $3.3 billion (inflation adjusted: Insurance Council of Australia); and
- The floods in eastern Australia in early 2011 cost about $12 billion in lost revenue (1.7% of GDP), mainly through lower coal and agricultural production.

In the past thirty years, the number of natural catastrophes has increased in Australia and around the globe.

A key challenge is to provide information on how extreme events are likely to vary under a changing climate.

A much stronger research effort is also needed to scale the information from global climate models to regional and local levels, where most extreme events occur.

Table 8. In 2010-11, the ACCSP's *Extremes* program addressed the above challenges and provided key information for helping Australia's decision makers and leaders to assess and minimise the risks with climate change.

Research program area	Project title	Target outcomes	What was delivered
6. Predicting Australia's future climate and its extremes	6.1 Regional climate projections science	• Credible future regional climates and their likelihood • Methodology for generation of future climate datasets that can be applied in impact and adaptation studies	• Journal articles drafted on the future climate storyline approach, application, and risk assessment for regionalisation, multi-variable and extreme aspects based on statistical analysis of global climate model output • Workshop report and journal article drafted on assigning likelihood to regional climate storylines using multiple lines of evidence (observed trends, physical arguments, etc.) • Plan for how to use the storyline approach for the next national projection release for Australia in combination with data projection services • Analysis begun of global climate model simulations and participation in IPCC *Fifth Assessment Report*
	6.2 Projections of storm surge and waves	• Hydrodynamic modelling capability that enables direct downscaling of CMIP5 time-slice experiments for projected changes in storm surges • Understanding of weather events that are the predominant cause of coincident rainfall-storm surge and erosion events along the Australian coastline	• Regional ocean model set up under current climate conditions using re-analysis data • Projections of extreme sea levels directly 'nested' in selected climate models for south-eastern Australia • International workshop in Europe in April 2011 to establish framework for internationally co-ordinated global wave projections to improve uncertainty estimates • A simple wave setup model that takes into account the wind and wave direction and coastline orientation to broadly quantify the additional contribution to coastal storm surges from wave setup
	6.3 Trends and projected changes in cyclonic rainfall	• Quantification of the contribution of cyclonic disturbances (e.g., tropical cyclones, monsoonal depressions, and cut-off lows) to Australian rainfall and extreme rainfall • Software for analysing the contribution of cyclonic disturbances to Australian rainfall using observational data that is suitable for use in future global and regional model outputs	• Between 1989—2009 there are increasing rainfall trends over the northern part of the continent while a large decreasing trend in rainfall is evident in the southeast • Analysis of annual rainfall between 1989-2009 show that tropical cyclones do not account for the increasing trend in north-west Australian rainfall • Closed lows provide over 70% of extreme rainfall to the majority of the coastline, with the exception of south-western Australia • There has been an increase in rainfall per tropical cyclone, particularly over the north of the region

Research program area	Project title	Target outcomes	What was delivered
6. Predicting Australia's future climate and its extremes	6.4 Climate projections for the coming decades consistent with recent trends	• Improved prediction of regional rainfall and temperature trends for the coming decades	• Assessment of recent trends in observational datasets acquired by the ACCESS evaluation group • Assessment of unforced simulations of other CMIP3 models • Refined time series of projected regional climate over next decades, including probabilistic ranges
	6.5 Enhancement of the Bureau of Meteorology statistical downscaling model	• A single multivariate downscaling model	• Evaluation and comparison of the performance of ACCESS with downscaled simulations with gridded observations on the same 5 km by 5 km grid • Maps of downscaled projections on a 5 km by 5 km grid for rainfall • Proposed strategy to deliver daily downscaled projections through a public interface being developed by the National Climate Centre
	6.6 Understanding of Southern Hemisphere climate projections using sensitivity experiments with the ACCESS model	• Better understanding of the response of the Southern Hemisphere to future changes in climate	• *Future climate change in the Southern Hemisphere: Competing effects of ozone and greenhouse gases* published in *Geophysical Research Letters* • Initial sensitivity experiments were designed using perturbations to sea surface temperatures • Climate version of ACCESS was implemented on the BoM's supercomputer and sea surface temperature perturbation experiments were completed • Initial comparison of ACCESS and the US National Centre for Atmospheric Research models shows contrasting results in their response to tropical warming
	6.7 Downscaled climate inputs for water resources assessment across large regions	• Assessment of the use of the weather research and forecasting regional climate model to downscale global climate models	• *Evaluating the performance of a 36 member WRF* physics ensemble over South-East Australia* to be published in *Climate Dynamics*. In press. **Weather Research and Forecasting*
	6.8 Dynamical ocean downscaling of climate change projections	• A method for using the eddy-resolving ocean carbon model of the Australian region to downscale climate change projections	• Downscaling of the CSIRO Mk3.5 A2 climate change projections for the 2060s for marine scientists wanting to investigate the impacts of climate change • Comparison and documentation of the climate change simulation of the physical and biological fields of the coarse-resolution model with the eddy-resolving model
	6.9 Projections of extreme winds for Australia	• Analysis of long-term observed wind speed over Australia	• *Long-term wind variability in Australia* published in the *Journal of Climate* • Report on a preliminary analysis of the projected wind climate over Australia using climate model scenario data • Report with recommendations to strengthen the wind observation network over Australia for climatic purposes
	6.10 Data delivery and *OzClim*	• Climate projections through enhancements to the *OzClim* scenario generator and training	• Enhanced climate projections through the *OzClim* scenario generator, and Enhanced Climate Futures software that allows generation of climate futures for up to six emissions scenarios, providing 'coherence' of projections • Planning and organisation for one-day climate projections workshops in capital cities to obtain feedback to inform future development and delivery of projections • *OzClim* (version 4.2) 'live' on 30 June 2011. Enhancements include user registration and questionnaire, dynamically downscaled data, user-defined regions for generating projected averages, and updated online guidance material • *Providing Application-specific Climate Projections Datasets: CSIRO's Climate Futures Framework* produced for the MODSIM conference held in Perth, Western Australia in December 2011
	6.11 Extremes research supporting adaptation for infrastructure planning	• Development of statistical models for analysing extremes that may be dependent on other extremes	• *A conditional extreme value approach to modelling multivariate weather extremes* to be submitted to *Geophysical Research Letters* • *A Bayesian Hierarchical Model for Estimating Depth-Area Curves* to be submitted to *Environmental Modelling and Software* • *A Markov model of hot spell activities* to be submitted to *Monthly Weather Review*

Science highlights

Preparing for next national climate change projections

To prepare for the next round of national climate change projections, scientists have begun analysing the CMIP5 climate model results. This is a considerable undertaking because CMIP5 is much larger than CMIP3, with up to 300 times the data. This means most of the processing needs to be done where the data is located at the Earth System Grid (ESG), not locally with the researchers. CSIRO researcher Dr Penny Whetton said a 'pipeline' was established to coordinate and facilitate the flow of processing for the large datasets extracted from the ESG. A toolbox was also created with a collection of programming codes and scripts that will grow as scientists start using them. To ensure stakeholders understand how to use the projections, scientists continued developing a new framework called Climate Futures to simplify how they communicate climate change projections, which are rapidly growing in their diversity. They also improved their probability projections that will be incorporated into the Climate Futures approach. By the end of 2011, a method should be in place for moving into the operational phase of producing the next national climate change projections.

This is a highlight of project 6.1 in Table 8.

Coordinated international wave modelling effort

A Coordinated Ocean Wave Climate Projections Working Group was set up in early 2011 to link international efforts in wave modelling. Closer to home, scientists established a hydrodynamic model spanning large stretches of the Australian coastline to determine coastal sea levels under the influence of downscaled winds and pressures from global climate models. They continued modelling the wave setup component of coastal sea level along the Victorian coast using climate-model-derived winds. CSIRO researcher Dr Mark Hemer said changes in wave climate may have large consequences on our coasts. However, relatively few studies on wave climate change have been undertaken. Coastal assessments need to be broadened beyond the impacts of sea-level rise to consider the potential influence of other dominant coastal drivers, such as wind-waves.

This is a highlight of project 6.2 in Table 8.

How will tropical cyclones affect water availability?

Scientists are trying to answer this question and others such as, how much do tropical cyclones and other cut-off low systems contribute to regional rainfall and rainfall extremes, is there a trend in the contribution of these lows to rainfall or rainfall extremes, and has the amount of rainfall associated with each tropical cyclone changed.

CSIRO researcher Dr Debbie Abbs said extreme rainfall can be produced by a number of weather systems such as cut-off lows and tropical cyclones. These weather events are the predominant cause of coincident rainfall-storm surge and coastal erosion events. The scientists analysed the trends in the precipitation efficiency of Australian region lows and tropical cyclones to evaluate if the amount of rainfall associated with each tropical cyclone has changed. CSIRO's Dr Sally Lavender said they found the most prominent result has been an increase in rainfall per tropical cyclone – particularly over the north of the region. That finding was based on data from 1989 to 2009.

This is a highlight of project 6.3 in Table 8.

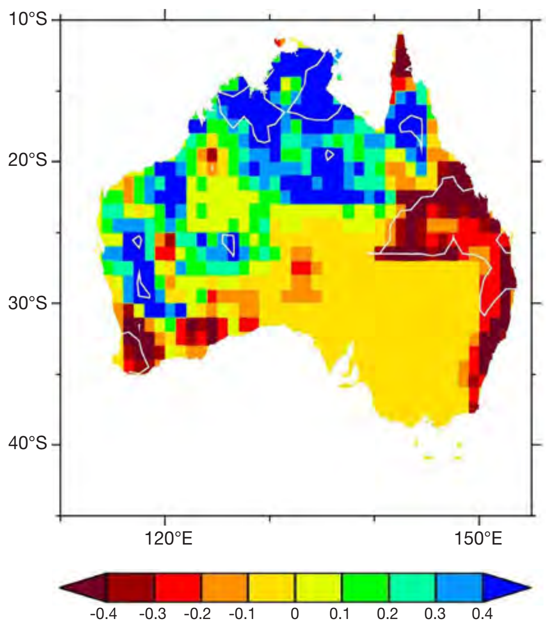


Figure 9. From 1989 to 2009, there has been an increase in rainfall (mm) per tropical cyclone – particularly over northern Australia.

Climate projections merged with observations

Scientists have begun probabilistic climate projections for the coming decades that are merged with present climate observations. CSIRO researcher Dr Ian Watterson said that using the past approach, sensitivity to global warming drove a trend that emerged from the expected climate for the current decade. However, much of Australia, especially the south-east, has been drier than expected. Any rainfall trend projections need to take into account recent trends, particularly declines in rainfall over the past two decades in south-east Australia and the global subtropics. These coincide with widespread declines in relative humidity in the new ERA Interim dataset (i.e. a recent 'reanalysis' – which puts together our best estimate of recent climate from day to day observations). This change may be due to the much larger overall warming of lower latitude land, relative to the ocean surface over this period.

This is a highlight of project 6.4 in Table 8.

Improved Bureau of Meteorology climate downscaling model

Projections of climate scenarios from the CMIP3 database are now available on a 5 km grid across Australia to assess rainfall and temperature changes. BoM researcher Dr Bertrand Timbal said that the BoM's downscaling model now provides regionally specific information that will improve the understanding and assessment of the impacts of climate change. Global climate models are not able to do this because the resolution is too coarse. High-resolution data is already being provided to colleagues dealing with impacts ranging from hydrology, crop modelling, human health, natural environment, energy, through to infrastructure management. Importantly, this work will deliver century-long projections when the CMIP5 database becomes available.

This is a highlight of project 6.5 in Table 8.

Southern Annular Mode projections variable

Projections have shown that increasing greenhouse gas emissions will affect the Southern Annular Mode (SAM) and are likely to decrease rainfall across southern Australia in winter. This change in the SAM is very robust across climate models; however, there is a large variation in the strength of the change. BoM researcher Ms Julie Arblaster said when she examined the climate model results she found the variations were related to the spread in climate sensitivity. That is, the models that showed the greatest warming had the largest changes in the SAM. Ms Arblaster and her colleagues dug deeper into the regional patterns that may affect this relationship. They found that the tropical upper tropospheric warming was more important than polar stratospheric cooling to the variation between models in the SAM trends.

Confidence in climate projections can be increased by understanding the physical mechanisms in the models that lead to the changes, and the sensitivity to changes in those processes.

This is a highlight of project 6.6 in Table 8.

Improving climate downscaling for water studies

An assessment of the weather research forecasting model used to downscale global climate model outputs for south-eastern Australia found that there was no single physics combination that performed best. The combination used by the weather research forecasting model has the largest impact on simulation of the more intense rainfall events. CSIRO project researcher Dr Marie Ekstrom said that this collaborative work with the Climate Change Research Centre at the University of New South Wales showed it is better to take a step-wise decision approach to identify the best schemes. This is a more robust way of choosing a scheme and identifying the combinations with better overall performance.

Dr Francis Chiew, who leads the wider climate impact on water research in CSIRO, said that better downscaling will improve predictions of the effects of climate change on hydrology and water resources. Reliable future water availability projections are critical for water planning to cope with climate variability and climate change.

This is a highlight of project 6.7 in Table 8.

Downscaling affects projection results

Downscaling of the CSIRO's climate change projection for the 2060s has shown that increasing the resolution affects the projections across Australia. CSIRO researcher Dr Richard Matear said that the surface warming of the CSIRO global climate projections (Mk3.5) is greatest in the Tasman Sea along the east coast of Australia where the water warms by 3ºC. He said the downscaled eddy-resolving model (Ocean Forecasting Australia Model with 0.1 degree horizontal resolution around Australia) shows that the maximum 3ºC warming now occurs along the path of the eastward flowing East Australian Current (approx. 35S). This difference in the models reflects the consequence of resolving the East Australia Current and eddies in the model to produce a significant change in the pattern of warming, which would alter the impact of climate change on the ecosystem of south-east Australia. To test this further, Dr Matear used atmosphere-only simulations driven by the projected 2060s' seasonal sea surface temperature of MK3.5 and the ocean model to assess the consequence on annual rainfall. He found that rainfall around Australia is significantly influenced by the fine details of the sea surface temperature warming.

These differences in the climate change projections highlight the need to further explore the consequence of using an eddy-resolving ocean model on climate change projections.

This is a highlight of project 6.8 in Table 8.

Taking the variability out of wind speed trends

Wind observations over Australia and reanalysis of wind speed measuring products are helping scientists understand the robustness and causes of variations in near-surface wind. CSIRO researcher Dr Alberto Troccoli said that like other meteorological variables such as temperature, wind observations are sensitive to the conditions in which they are observed – for example, where the instrumentation sits relative to topographical features, vegetation and urban developments. After a thorough quality control of observations, Dr Troccoli found that the wind speed trends over Australia are sensitive to the height of the station, with winds measured at two metres above the ground displaying an opposite trend to those at 10 metres. At the latter height, light winds tend to increase more rapidly than the mean winds, whereas strong winds increase less rapidly than the mean winds. At two metres high, light and strong wind trends vary in line with the mean winds. This work shows a number of challenges with the consistency of the observations during their period of operation and between sites across Australia.

The quality of future wind observational datasets will depend on having consistency between sites, particularly with respect to measurement procedure, maintenance of instrumentation and detailed records of the site history.

This is a highlight of project 6.9 in Table 8.

Meeting the demand for climate projections

The demand for climate projections is continuing to grow. National climate projections are publicly available through the *Climate Change in Australia* and *OzClim* websites. However, there are many requests for information not available from these sites. In 2010-11, CSIRO researcher Mr John Clarke received approximately 60 requests for projections data. He said a lot of these requests require manual production of projections that are tailored for specific purposes. There is also considerable demand for advice on how to use the projections information appropriately. Since CSIRO and BoM released the national climate change projections in 2007, there has been consistent, strong use of the *Climate Change in Australia site.*

During the reporting year, workshops for projections users in five of eight capital cities enabled people to share their experiences about how the projections have been used, what has worked well, what hasn't worked well, and what's needed from the future projections. This will help provide more reliable projections, better guidance material, easier data access, and user-friendly tools when the new national climate change projections are released in 2014. The three remaining workshops will be held in August and September 2011.

This is a highlight of project 6.10 in Table 8.

Simulations show potential for larger flooding events

Modelling simulations from the analysis of observed rainfall and storm surge data indicate the potential for larger flooding events than those we have seen to date. Climate extremes such as heavy rainfall or heatwaves have significant implications for infrastructure planning and management. However, when extremes occur together, the impact can be even more severe. CSIRO statistician Mr Mark Palmer said a single extreme event can have different impacts on separate regions of the country. A recent example is the devastating 2011 bushfires in Perth that were fanned by strong winds from the remnants of Cyclone Yasi, which caused severe damage in Queensland and flooding in Victoria. Mr Palmer's team of statisticians has developed ways of characterising Australian climate extremes, particularly rainfall, and measures of rainfall variability that can be used by decision-makers. More realistic and flexible ways of modelling and analysing hot spells and heat waves have also been developed. This modelling will help decision-makers assess and minimise the risks associated with concurrent extremes.

This is a highlight of project 6.11 in Table 8.

Key climate **challenge:** Communication

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

This means that there is an even greater need for clearer and more effective communication of the ACCSP's world–class research findings.

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, agencies and instrumentalities, local government, industry and to the general public. It also generates research cited by the IPCC, which positions Australia strongly in the international climate science community.

Outcomes from ACCSP research are communicated through journal papers, this report, workshops, conferences, science information papers, fact sheets, brochures, video clips, social media, and websites (listed in Tables below).

Table 9. In 2010-11, the ACCSP's *Communication and co–ordination* program helped inform Australia's decision makers about the changes occurring due to rising concentrations of greenhouse gases and the likely future changes to climate. It also provided information and events to help stakeholder understanding of the causes, nature, timing and consequences of climate change.

Research program area	Project title	Target outcomes	What was delivered
Communication and co–ordination	7.1 ACCSP – Program management, co–ordination and communication	• Oversight of the ACCSP for BoM and CSIRO • Internal and external communication of the ACCSP findings to the DCCEE, BoM, CSIRO, CAWCR, other Australian Government departments, State Government, research agencies, industry and the public	• Oversight of project selection process for 2011–12 • Development and delivery of annual CSIRO–BoM project proposals for the ACCSP • Regular reports to the DCCEE on the progress of deliverables throughout the year through the annual report and quarterly traffic light reports • GREENHOUSE 2011 conference in Cairns, Queensland, from 4–8 April 2011 • ACCSP annual science meeting for DCCEE, 8–9 June 2011 • Publications including workshop and meeting reports, and high-level briefing preparation • Three workshops (planning, November 2010; communication, December 2010; and CMIP5 in April 2011)

Science highlights

Delivering Australian climate change science

BoM and CSIRO climate change scientists have undertaken research at various laboratories and field sites across Australia and on the high seas. They have addressed a suite of uniquely Australian climate change science issues and improved our broader understanding of global climate change. ACCSP Manager Mr Paul Holper said the science program begins each year with the scientists comparing findings, identifying gaps and needs and then developing proposals. There is strong encouragement to collaborate on larger, consolidated projects. A selection panel assesses projects based on their quality and relevance. Sound program management ensures good internal communication, encourages collaboration between researchers and facilitates completion and delivery of climate science.

GREENHOUSE 2011 – the science of climate change

A significant event in 2011 was the sixth GREENHOUSE conference, held in Cairns from 4-8 April. Leading scientists from Australia and around the world presented the latest climate change developments to conference delegates. The conference explored various climate change themes: including trends, modelling, projections, observations, adaptation, communication, and policy and economic implications. It attracted:

- more than 470 delegates
- 29 keynote speakers/panellists
- almost 150 presentations
- 11 exhibits
- 60 parallel presentations
- more than 90 climate science posters
- participants from 26 countries
- significant sponsor support from nine organisations

Climate Change book launched

- On the first day of the conference, Dr Megan Clark launched CSIRO's new book: *Climate Change – Science and Solutions for Australia*. It draws on the latest peer–reviewed literature contributed by thousands of researchers in Australia and internationally. An electronic version of the book, which features contributions from ACCSP researchers, is free and can be downloaded from www.csiro.au/climate-change-book.

Media coverage

The conference received strong media coverage. There were 19 representatives from key media and more than 60 climate change articles published in the print and electronic media during the conference. Conference twitter followers quadrupled and within a few days there were almost 150 followers. See Appendix 1 for a list of ACCSP media releases distributed in the reporting year.

Key messages

A video speech by the Hon. Greg Combet, Minister for Climate Change and Energy Efficiency, highlighted that robust science was important for understanding the impact of climate change and for communicating effectively and accurately.

Prof. Ross Garnaut, from The University of Melbourne, was a keynote speaker who said that when we look at the science, there is very little doubt that there is a human footprint in the planet's warming.

Dr Bruce Mapstone, Chief of CSIRO Marine and Atmospheric Research, closed the conference, which encouraged open and factual discussion based on mainstream science and the need to communicate clearly and simply.

The next GREENHOUSE conference will be held in Adelaide in 2013.

This is a highlight of project 7.1 in Table 9.

Figure 10. Keynote speaker Prof. Ross Garnaut (The University of Melbourne) addressing GREENHOUSE 2011.

Figure 11. Mr Graeme Anderson (Victorian Department of Primary Industries) told a packed room of more than 100 delegates at GREENHOUSE 2011 that extension activities were critical for providing new products and services to help farmers find ways to stay productive and sustainable within a changing and more variable climate.

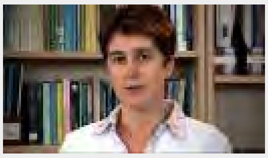
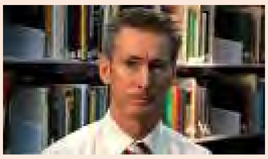
Table 10. The following media releases arose directly from ACCSP research or publicised relevant work.

Media release	Date distributed	Web link
We will need to adapt to rising sea levels	10 Oct 2010	http://www.csiro.au/news/We-will-need-to-adapt-to-rising-sea-levels.html
Going hi-tech to probe deeper into the oceans	14 Oct 2010	http://www.antarctica.gov.au/media/news/2010/going-high-tech-to-probe-deeper-into-oceans
2010 Study indicates a changing climate in the south-east	22 Oct 2010	http://www.csiro.au/news/Study-indicates-a-changing-climate-in-the-south-east.html
Global CO2 emissions may set a record this year	22 Nov 2010	http://www.csiro.au/news/Global-CO2-emissions-may-set-a-record-this-year.html
SEQ drought likely caused by climate variability	26 Nov 2010	http://www.csiro.au/news/SEQ-Drought.html
Tasmanian scientists expand their view of the oceans	14 Dec 2010	http://www.csiro.au/news/Tasmanian-scientists-expand-ocean-view.html
Climate is warming – despite 'ups and downs'	28 Dec 2010	http://www.csiro.au/news/climate-is-warming-despite-ups-downs.html
Mertz Glacier under the microscope	4 Jan 2011	http://www.antarctica.gov.au/media/news/2011/mertz-glacier-under-the-microscope
CO2-chomping microbes battling for ocean iron	24 Jan 2011	http://www.csiro.au/news/CO2-chomping-microbes-battling-for-ocean-iron.html
GREENHOUSE 2011: the science of climate change	28 Jan 2011	http://www. greenhouse2011.com
East coast gliders yield valuable marine life data	28 Feb 2011	http://www.csiro.au/news/East-Coast-gliders-yield-valuable-marine-life-data.html
GREENHOUSE 2011: predicting climate change	4 Mar 2011	http://www. greenhouse2011.com
GREENHOUSE 2011: integrating knowledge is key	14 Mar 2011	http://www. greenhouse2011.com
When times are tight, focus on adaptation	22 Mar 2011	http://www.csiro.au/news/climate-change-local-impacts.html
We need concrete answers to climate change effects	23 Mar 2011	http://www.csiro.au/news/we-need-concrete-answers-to-climate-change-effects.html
Changing climate, changing ecology	30 Mar 2011	http://www. greenhouse2011.com
Climate change – a Pacific island perspective	31 Mar 2011	http://www. greenhouse2011.com
Ocean depth and ice no longer a barrier to climate – latest climate change information captured in http://www.csiro.au/news/New-Climate-Change-book.html new CSIRO book	4 Apr 2011	http://theconversation.edu.au/ocean-depth-and-ice-no-longer-a-barrier-to-climate-science-688
Latest climate change information captured in new CSIRO book	4 Apr 2011	http://www. greenhouse2011.com
Work begins on Australia's best yet climate projections	5 Apr 2011	http://www.csiro.au/news/Work-begins-on-Australias-best-yet-climate-projections.html
Southern Ocean acidification report card released	8 Apr 2011	http://www.antarctica.gov.au/media/news/2011/southern-ocean-acidification-report-card-released
Record greenhouse gas levels: see for yourself	20 Jun 2011	http://www.csiro.au/news/Record-greenhouse-gas-levels.html

Table 11. In 2010-11, the ACCSP communicated climate change science and related information to the wider community via the following web sites:

What	Organisation	Web address
About the ACCSP	CSIRO	www.csiro.au/org/Australian-Climate-Change-Science-Program.html
About the ACCSP	DCCEE	www.climatechange.gov.au
The science of climate change	CSIRO, BoM, DCCEE	www.climatechange.gov.au
Observed Australian climate trends	BoM	www.bom.gov.au/climate/change
Australian national and state-wide climate projections	CSIRO, BoM, DCCEE	www.climatechangeinaustralia.gov.au
Australian climate scenario generator	CSIRO	www.csiro.au/ozclim – climate scenario generator
Greenhouse gas emission measurements	CSIRO	www.csiro.au/greenhouse-gases

Table 12. In 2010-11, the ACCSP published video clips of its scientists answering commonly asked climate change questions on the CSIRO web site:

Scientist	Hot topic	Location
 Dr David Etheridge	How do we know about greenhouse gas changes in the past?	http://www.csiro.au/news/Climate-Change-Palaeoclimatic-Context.html
 Dr David Jones	Has global warming stopped?	http://www.csiro.au/news/Has-Global-Warming-Stopped.html
 Dr Helen Cleugh	How important is water vapour as a greenhouse gas?	http://www.csiro.au/news/Climate-Change-Water-Vapour.html
 Mr Kevin Hennessy	Is there an inconsistency between observed and modelled patterns of warming in the lower atmosphere?	http://www.csiro.au/news/Are-Climate-Models-Inconsistent.html
 Dr Mike Raupach	Can the warming of the 20th century be explained by natural processes?	http://www.csiro.au/news/Climate-Variability.html
 Dr Penny Whetton	How reliable are climate models?	http://www.csiro.au/news/Reliability-Climate-Models.html

Appendix 1: Project list

Table 13. In 2010-11, the ACCSP delivered 33 projects across seven program areas:

Key climate challenge	Research program area	Project title	Lead 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
Atmosphere	2. Land & air observations and processes	2.1 Estimating Australian greenhouse gas sources from biomass burning	CSIRO
		2.2 Using data from the Australian flux network (TERN/OzFlux) and Tumbarumba flux station for ecosystem analysis and model	CSIRO
		2.3 ACCSP aerosol	CSIRO
		2.4 Reducing uncertainty in climate sensitivity and climate projections	BoM
Oceans & coasts	3. Oceans & coasts	3.1 Southern Ocean carbon dioxide sink	CSIRO
		3.2 Ocean carbon and acidification	CSIRO
		3.3 Ocean climate data partnerships	CSIRO
		3.4 Ocean climate processes: understanding ocean control of global and Australian climate	CSIRO
		3.5 Global sea-level rise: Reducing uncertainty and improving projections	CSIRO
		3.6 Australian baseline Sea level monitoring array	BoM
Water	4. Modes of climate variability and change	4.1 Tropical cyclone database review and repair	BoM
		4.2 Impact of climate change on the risk of formation of East Coast Lows	BoM
		4.3 The Australian monsoon: Processes, projections and extreme rainfall	BoM
		4.4 Global warming, the Walker Circulation and El Niño/La Niña-Southern Oscillation	BoM
		4.5 The response of Indo–Pacific ocean variability to climate change and its impact on Australian climate	CSIRO
		4.6 Attribution and projection of Australian climate, rainfall and large scale modes	BoM & CSIRO
An Australian climate modelling system	5. Earth system modelling and data integration	5.1 Development of the ACCESS coupled modelling system	BoM
		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 Regional climate projections science	CSIRO
		6.2 Projections of storm surge and waves	CSIRO
		6.3 Trends and projected changes in cyclonic rainfall	CSIRO
		6.4 Climate projections for the coming decades consistent with recent trends	CSIRO
		6.5 Enhancement of the Bureau of Meteorology statistical downscaling model	BoM
		6.6 Understanding of Southern Hemisphere climate projections using sensitivity experiments with the ACCESS model	BoM
		6.7 Downscaled climate inputs for water resources assessment across large regions	CSIRO
		6.8 Dynamical ocean downscaling of climate change projections	CSIRO
		6.9 Projections of extreme winds for Australia	CSIRO
		6.10 Data delivery and OzClim	CSIRO
		6.11 Extremes research supporting adaptation for infrastructure planning	CSIRO
Communication	7. Communication & coordination	7.1 ACCSP – Program management, co–ordination and communication	CSIRO & BoM

Appendix 2:
Other partners

In addition to its program of 33 climate science and other projects, the ACCSP collaborated in specific research projects with the following partners:

National

- Antarctic Climate and Ecosystems Cooperative Research Centre
- Australia's Integrated Marine Observing System
- Australian Institute of Marine Science
- Australian Nuclear Science and Technology Organisation
- National Computational Infrastructure
- Queensland Climate Change Centre of Excellence
- South Eastern Australia Climate Initiative
- The University of Melbourne
- University of New South Wales
- University of Sydney
- University of Tasmania – The Institute of Marine and Antarctic Studies
- University of Wollongong

International

- Alfred Wegener Institute for Polar and Marine Research, Germany
- Atlantic Oceanographic and Meteorological Laboratory, USA
- Centre for Ice and Climate, University of Copenhagen, Denmark
- College of Global Change and Earth Systems Modelling, Beijing Normal University, China
- Geophysical Fluid Dynamics Laboratory, Princeton, New Jersey, USA
- Institute of Atmospheric Physics, Chinese Academy of Sciences, China.
- International Argo program (more than 15 countries – http://www.argo.ucsd.edu/)
- Japan Agency for Marine Science and Technology
- Low Temperature research laboratory, Japan
- MetOffice, Exeter, UK
- National Center for Atmospheric Research, USA
- National Institute for Environmental Studies, Japan
- National Institute for Water and Atmosphere, New Zealand.
- National Ocean and Atmospheric Administration, USA
- National Oceanic and Atmospheric Administration, USA
- National Oceanographic Data Centre, USA
- Pacific Climate Change Science Program, Australia
- Pacific Marine Environmental Laboratory, USA
- Scripps Institution of Oceanography, USA
- University of Tohuku, Japan

Appendix 3: Peer-reviewed publications

In 2010-11, ACCSP researchers produced or contributed to 147 publications.

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.

Greenhouse gases

Anderson RG, Canadell JG, Randerson JT, Jackson RB, Hungate BA, Baldocchi DD, Ban-Weiss GA, Bonan GB, Caldeira K, Cao L, Diffenbaugh NS, Gurney KR, Kueppers LM, Law BE, Luyssaert S, and O'Halloran TL. 2011. Biophysical considerations in forestry for climate protection. *Frontiers in Ecology and the Environment,* **9**, 174-182, doi:10.1890/090179.

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Appendix 4: Other publications

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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.