



Meteorological and Related Research

Output Group 1.2 - Meteorological and Related Research – comprises a single Major Output ‘Meteorological and Related Research’.

The Meteorological and Related Research Output delivers research with a strategic focus, on responding to new challenges in the advancement of meteorological, hydrological and oceanographic science, and applying that science to the needs of the Australian community, as well as a tactical emphasis, underpinning the Bureau’s systems and services.

The Bureau has transformed the way in which it delivers this Major Output through two* significant initiatives developed over the past few years. The first is the establishment with CSIRO of the Centre for Australian Weather and Climate Research (CAWCR) as a jointly operated research venture focussing on weather, climate and earth system science. The Centre is the main organisational unit tasked with generating research outputs for the Bureau; its work is complemented by research and development undertaken in the Bureau’s Regional Offices, the National Meteorological and Oceanographic Centre, and other areas of the Bureau.

The second initiative is the Australian Community Climate and Earth System Simulator (ACCESS), a major earth system modelling activity. It is an important component of the work of CAWCR, but one which is being carried out in partnership with the university sector and others. ACCESS will deliver a new generation of modelling and model systems infrastructure which will underpin Bureau services on a range of timescales, enabling advanced numerical weather and ocean prediction, dynamical seasonal forecasting models, and the ability to simulate future and past climate change, particularly as it manifests in the Australian region.

* Research for Water Information Services is provided through the Water Information Research and Development Alliance (WIRADA). These activities, and activities related to ionospheric research, are reported in the chapters titled Water Information Services and Meteorological and Related Data, respectively.

Output Performance Information 2008-09

Output performance is measured against a number of performance targets. The results achieved for 2008-09 are provided below along with a commentary on significant variations.

Description of Output	Research, in partnership with CSIRO, into climate, atmospheric, land, and marine processes, in particular those processes that drive climate variability and change.
Contribution to Outcome	Advancement of meteorological science and understanding of the mechanisms of Australian weather and climate.
Key result	A contribution to earth systems science that is recognised for its innovation and scientific excellence nationally and as a world leader in the field.

Key Performance Indicator	Target	Result
Research is recognised for the quality and extent of its contribution to national and international meteorological and related sciences.	Number of awards - 3	5
	Number of international visitors - 20	33
	Number of peer-reviewed publication articles - 65	108
	Number of non-peer reviewed publication articles - 90	118
	Number of international meetings convened - 3	3
	Number of memberships on eminent scientific panels - 12	25
Research contributes to the knowledge base relevant to Australian weather and climate.	Number of collaborative projects managed - 12	14
	Number of innovations taken up externally - 2	1
	Number of inventions (new technology) - 1	1
	Number of seminars held (internally organised) - 50	39
Research is responsive to national priorities and the Bureau's operational needs.	Number of new developments/innovations (tests, trials) - 4	6
	55% of research effort to address National Research Priorities	Achieved
	30% of research budget from external sources	38.7%
Research impacts the efficiency and effectiveness of relevant systems and services within the Bureau.	Number of responses/advice for extreme weather events - 5	4

Research impacts national and international scientific debate within its field(s) of expertise.	Number of scientists as lead or contributing authors in Intergovernmental Panel on Climate Change and equivalent assessments - 5	5
	Number of invitations to present at national meetings/workshops/conferences including keynote addresses - 40	47
	Number of collaborative projects - 75	90
Research is innovative and policy relevant, nationally and internationally.	Number of people directly involved in national science forums and working groups - 10	12
	High quality input to question time briefs - 5	2
	All requests for advice met on time	Achieved
	Scientific integrity of systems and services maintained (100% still operating)	Achieved
	Positive response to the National Research Priorities (NRP) report from the Office of the Chief Scientist – number of issues identified no more than one.	n/a (see Note 1)
Number of communications (briefings, media, etc.) - 25	46	

Notes:

(1) Input to reports on the National Research Priorities was not requested by the Office of the Chief Scientist during 2008-09.

Comments on Output Performance

The Bureau hosted a large number of visiting scientists, with long-term visitors (those staying for more than one week) coming from countries including Canada, China, France, Germany, Indonesia, New Caledonia, the United Kingdom and the United States. The number of published articles was higher than the previous year and exceeded the targets significantly. This may reflect the transition of CAWCR to a fully functional state, after the considerable administrative effort during 2007-08 in establishing the centre. An increase in the proportion of the research budget for 2008-09 from external sources reflects the growth in external research collaborations and projects involving the Bureau.

Many visiting scientists gave presentations at the regular research seminar series held at the Bureau's Head Office in Melbourne, and contributed to international meetings hosted by CAWCR, including the Second CAWCR Modelling Workshop, and a workshop on ensemble prediction and data assimilation. The number of internally organised seminars held in the Bureau was nevertheless below target and requires a stronger focus in the coming year.

Media briefings and enquiries again exceeded expected levels, and reflected a wide range of public concerns during the year, including drought, the decline in rainfall in southeastern Australia, the devastating fire season in the 2008-09 summer, the involvement of CAWCR staff in forecasting and 'nowcasting' (very short-range forecasting) support at the Beijing Olympics, regional climate projections, coral bleaching on the Great Barrier Reef and severe weather events such as destructive thunderstorms in Brisbane and surrounds.





Bureau scientists collaborate with Chinese scientists from the China Meteorological Administration at the Beijing Meteorological Bureau during the Beijing Olympics Forecast Demonstration Project which highlighted international developments in 'nowcasting'.

Achieving the Outcome

The Meteorological and Related Research Major Output was delivered through two component outputs: Earth System Modelling and Climate Research; and Weather, Oceans and Environment Research. The contributions reported below reflect the collaborative efforts of all CAWCR scientists to Bureau outputs, whether employed by the Bureau or by the CSIRO.

CAWCR's integrated research capabilities are organised into eight research groups:

- ACCESS;
- Climate Change;
- Seasonal and Inter-annual Prediction;
- Ocean Observation and Assessment;
- Weather and Environmental Prediction;
- Atmosphere and Land Observation and Assessment;
- Ocean Prediction; and
- Complex Systems Science.

Earth System Modelling and Climate Research

The Earth System Modelling and Climate Research output draws on the work of four CAWCR research groups: ACCESS, Climate Change, Seasonal and Inter-annual Prediction and Ocean Observation and Assessment. The ACCESS research group leads CAWCR devel-

opment of a world-competitive coupled climate and earth system simulator and associated modelling systems. The objective of the Climate Change group is to understand and project future climate change and its impacts so as to inform policy and decision-making, including the development of appropriate adaptive responses by the community. The Seasonal and Inter-annual Prediction research group delivers new knowledge and applications that inform policy for managing Australia's environmental resources and decision-making in climate-sensitive industries on monthly to seasonal timescales. The Ocean Observation and Assessment group aims to create the infrastructure and knowledge to monitor, observe and understand the key processes that drive variability and change in Australia's marine and deep ocean waters.

Major Developments 2008-09

- The concept of ACCESS is founded on the coupling of several different computer models dealing with different components of the earth system, enabling the development of prediction capability on a range of time and space scales from short-term weather forecasting to very long-term changes in the climate, and encompassing a range of natural resource systems (rainfall, soil water, vegetation). During 2008-09 development and extensive testing of the shorter-term numerical weather prediction component of ACCESS was completed. This component encompasses modelling of the atmosphere, including the routine assimilation of a wide variety of data including satellite data into the system, and is based on the Unified Model developed by the UK Met Office (UKMO). Testing of both global and Australian region systems showed a large improvement in skill relative to the current Bureau operational modelling systems (see Figure 9). When fully operational, these developments will produce more detailed and accurate forecast guidance products for use by weather forecasters, as well as additional feedback on the operation of the model itself (for example, suspected erroneous observations which may indicate equipment malfunction). This will enable Bureau staff both to provide the community with more accurate forecasts and warnings, and to more objectively assess the confidence they have in the forecasts and warnings issued.
- The Second CAWCR Modelling Workshop was held in November, with the theme of 'High Resolution Modelling'. Invited speakers and eminent scientists attended from Australian and international research centres including the University of Rhode Island in the United States, the UKMO and Proudman Oceanographic Laboratory in the United Kingdom. Themes discussed included numerical weather prediction, coupled weather modelling, climate modelling, ocean modelling and user expectations. These annual workshops provide a forum for exchange of scientific ideas, assist with driving progress in scientific research, and enable collaborative approaches which are crucial to achieving advances in modelling the earth climate system.
- The Atmospheric Model Intercomparison Project (AMIP) is a project of the World Climate Research Programme that provides the international climate modelling community with a means of testing and comparing climate models. Several ACCESS scientists were involved in the completion of AMIP model runs and the subsequent evaluation of model performance. Two successful workshops were held at the Bureau of Meteorology to progress AMIP-related research with more than 50 participants from CAWCR and the university sectors.



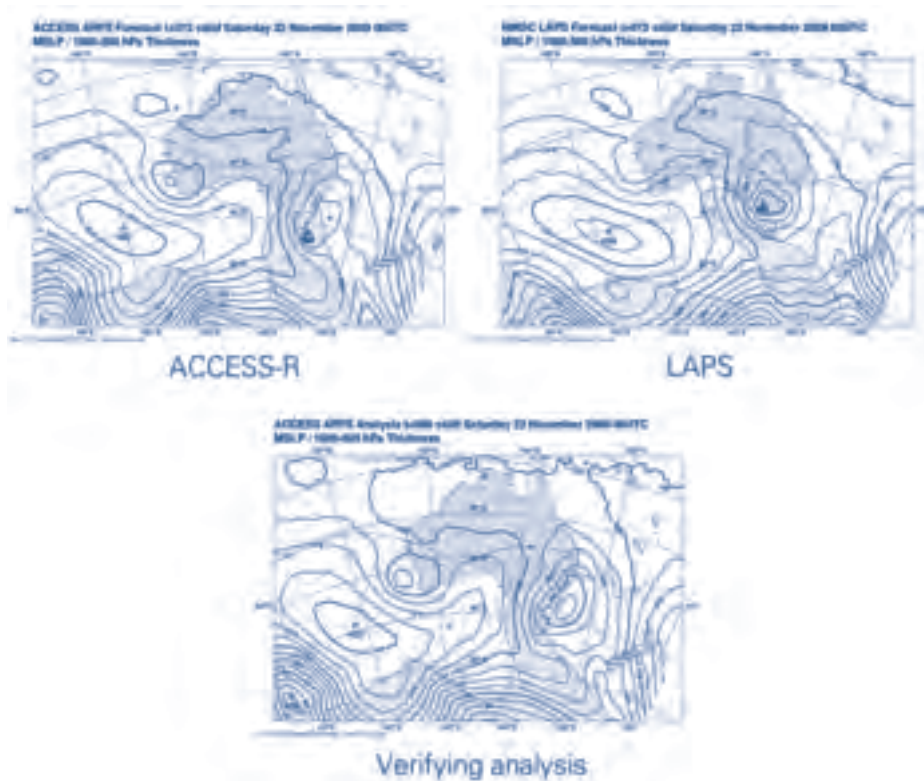


Figure 9. The ACCESS numerical weather prediction suite is expected to improve weather forecasts. For the Gippsland, Victoria flooding event of 22 November, the 72-hr ACCESS mean sea level pressure (MSLP) prediction (top left) displays excellent performance compared with output from the older Limited Area Prediction System (LAPS - top right). The verifying analysis is at the bottom. While rainfall was forecast by LAPS, it was not at sufficient intensity to indicate flooding, whereas ACCESS provided good prediction of the motion and development of the Bass Strait low pressure system, and guidance for high rainfall over Gippsland. Experience to date indicates that ACCESS forecasts extratropical cyclogenesis events particularly well.

- The South Eastern Australian Climate Initiative (SEACI) is a three-year, \$7 million research program, launched in 2006 as a partnership involving government and industry, and investigating the causes and impacts of climate change and climate variability across south-eastern Australia. At the conclusion of the first phase of the SEACI project in December, all milestones set for the project had been achieved, with associated significant advances in scientific understanding. For example, assessment of the linkages between rainfall variability and change and a range of climate drivers such as the Southern Annular Mode (SAM), the Indian Ocean Dipole (IOD), El Niño-Southern Oscillation (ENSO) and subtropical ridge, concluded that the reductions in rainfall over recent years, which are particularly significant in the autumn season, are consistent with impacts from human-induced climate change. SEACI is managed by the Murray-Darling Basin Authority, with the Bureau

of Meteorology and CSIRO as research partners. The contract was to cease in December, but was extended to June pending the conclusion of discussions and negotiations on a possible new contract covering a further phase of the project.

- A method for producing regional climate change projections from broader-scale computer model output was extended to the whole of Australia and a graphical presentation facility was developed for results from the Statistical Downscaling Model that provides these downscaled projections (see Figure 10). These advances were among the outcomes of the Australian Climate Change Science Program, funded and administered by the Department of Climate Change. Downscaled projections covering a range of elements (e.g. rainfall, evaporation and temperature) are now available to Bureau staff in all Regional Offices to assist them in answering queries from members of the community with regard to the impacts of climate change in their region of the country.
- Australia experiences high interannual climate variability that affects all facets of natural resource management. The Predictive Ocean Atmosphere Model for Australia (POAMA) is a seasonal to interannual forecast system based on a coupled ocean-atmosphere model and data assimilation systems covering ocean, atmosphere and land observations.

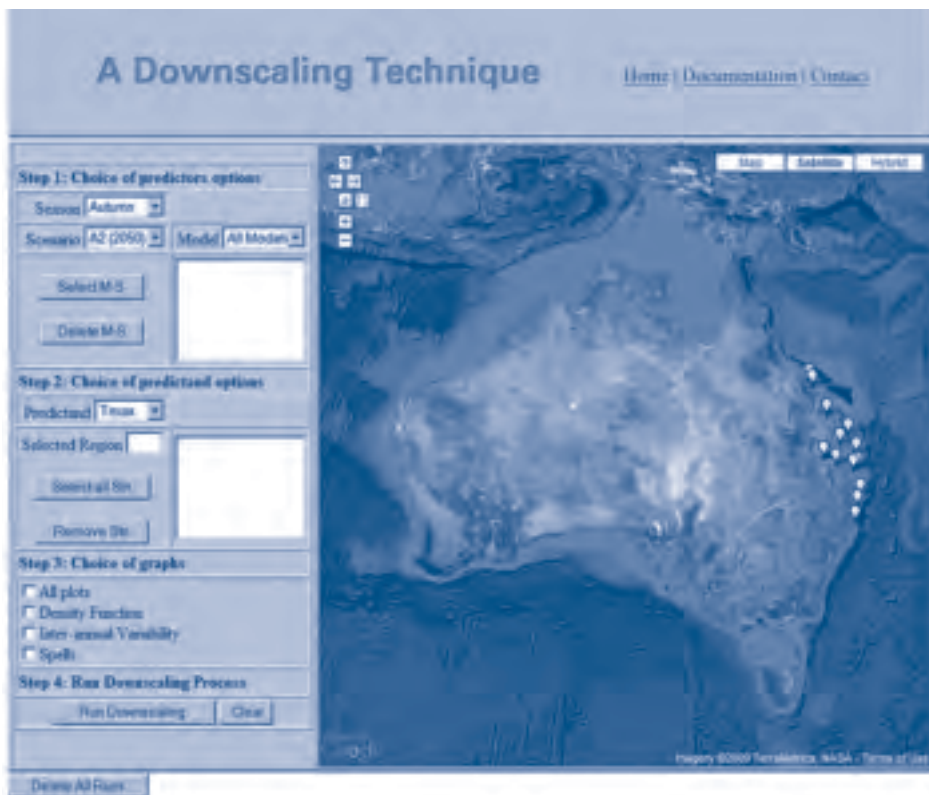


Figure 10. The graphical interface developed for the presentation of output from the Statistical Downscaling Model, with projections of climate change for localities across Australia available via a web tool, for a range of local weather related variables such as rainfall, evaporation and temperature.



A new ocean re-analysis covering the period 1977-2006 was completed with the POAMA Ensemble Ocean Data Assimilation System (PEODAS), and used in a series of model forecasts undertaken for past climate conditions, or 'hindcasts', aimed at reproducing the evolution of past ocean conditions over that period. This enabled calibration of the real-time forecasting system which in turn produced significant improvements in forecast accuracy, most notably with regard to the occurrence of El Niño events as shown by sea surface temperatures. Improvements in seasonal forecasting are of benefit to a range of stakeholders including those in Australia's agricultural and water resources sectors.

- Considerable progress was made with the coupling of the land-surface model CABLE (CSIRO Atmosphere-Biosphere Land Exchange model) to the UKMO Unified Model within ACCESS. The eventual goal of this work is replacement of the UK-developed land-surface model currently used in ACCESS with an Australian-developed version which provides better representation of the carbon cycle and will both improve the accuracy of the model predictions and provide a foundation for further collaborative work on the system by the Australian research community. Work on the addition of the ocean and sea ice modelling components of ACCESS was also completed, with the fully coupled earth system model made ready for the commencement of the next phase. This will involve testing and fine-tuning the coupled model to ready it for operational use including the very lengthy model runs capable of producing climate change projections over hundreds of years.

Weather, Oceans and Environment Research

The Weather, Oceans and Environment Research output spans four CAWCR research groups: Weather and Environmental Prediction, Atmosphere-Land Observation and Assessment, Ocean Prediction and Complex Systems Science. The Weather and Environmental Prediction research group aims to improve understanding of atmospheric processes, and develop and apply numerical weather prediction systems to advanced weather forecasting and related environmental services, such as severe weather and air pollution hazards. The objective of the Atmosphere-Land Observation and Assessment group is to develop the techniques and knowledge to monitor, observe and understand atmospheric and land processes, their interaction, and the role they play in the Australian environment. The Ocean Prediction research group aims to describe, model and predict the variability of the oceans and the surface marine environment of the Australian region and, in conjunction with the Ocean Observation and Assessment group, to develop an understanding of the processes and mechanisms that determine the ocean's role in climate and climate change. The Complex Systems Science group facilitates the development and use of techniques that will expand our knowledge and understanding of complex systems, and help society make better informed planning and management decisions.

Major Developments 2008-09

- The Next Generation Forecast and Warning System (NexGenFWS - encompassing the Graphical Forecast Editor), which was under investigation and development within the Bureau during 2008-09, produces forecasts for a grid of points across the whole of Australia, largely automatically, based on the output of numerical prediction models. Development of three major components of the NexGenFWS were completed to a level sufficient to

support a demonstration pilot of the system implemented for Victoria in October. The developments completed were: 1) a facility for the generation of a 'first-guess' field of forecast parameters using the Operational Consensus forecast guidance system which combines output from a range of numerical weather prediction models, 2) a set of 'smart tools', based on the forecast processes used by human forecasters, which allow systematic, efficient adjustment of the 'first-guess' forecast fields in line with the known physics of the atmosphere to take better account of such features as topography and other influences on the weather in particular geographic areas; and 3) natural language generation modules, which take the final forecast grids and produce worded forecasts in natural English – a system based on the infrastructure developed in the US but with a large number of modifications to allow for use of more complex and sophisticated forecast terminology. The development of the NexGenFWS and its pilot implementation in Victoria trialled the potential of NexGenFWS to provide more detailed forecasts than is currently possible for localised areas covering every part of Australia.

- The Beijing Olympic Games were the forum for the demonstration of experimental developments in very short-range forecasting (nowcasting) of rainfall and thunderstorms, and verification of those 'nowcasts' in real time. New products showing probabilities of thunderstorm occurrence across the Beijing basin, based on the output of an international ensemble of different thunderstorm tracking systems, were generated in two versions, with and without human input, with the version including human input shown to be superior. In addition, ensemble rainfall predictions were used to produce automatic flash flood warning guidance. An automatic forecast verification system which gave forecasters feedback on the success of their thunderstorm forecasts as the forecast situation unfolded was also trialled. These products were showcased at the Games via the World Weather Research Program Beijing 2008 Forecast Demonstration Project – an international demonstration of the state-of-the-art capability of 'nowcast' systems where both competitors and organisers alike can make critical use of highly-detailed and up-to-the-minute information on expected weather. This was the second such project in which the Bureau has been involved; the first was held during the 2000 Olympic Games in Sydney.
- Work continued on fire weather forecasting developments, including studies of the influence of atmospheric instability on fire behaviour and dry lightning which is a critical factor in starting bushfires, and the development of trial versions of tools for operational forecasters based on this work. Fire weather tools developed in CAWCR improve the accuracy, timeliness and usefulness of forecasts produced for emergency managers and the community during actual bushfire situations. The tools developed were deployed in the 2008-09 summer bushfire season, including in the production of the critical forecasts done for 'Black Saturday' on 7 February.
- Improved guidance was provided for Australia's aviation industry via enhancements to forecast products for both in-flight and ground-based operations. The Automated Thunderstorm Alert Service (ATSAS) provides alerts of possible lightning to ground-based airport staff at specified airports (Figure 11). The reliability of alerts was improved during 2008-09 through the use of merged radar data from more than one nearby radar location, so that the alerts continue in a seamless fashion should one local radar fail. Development also commenced on the use in the ATSAS of lightning data from commercial lightning detection systems.



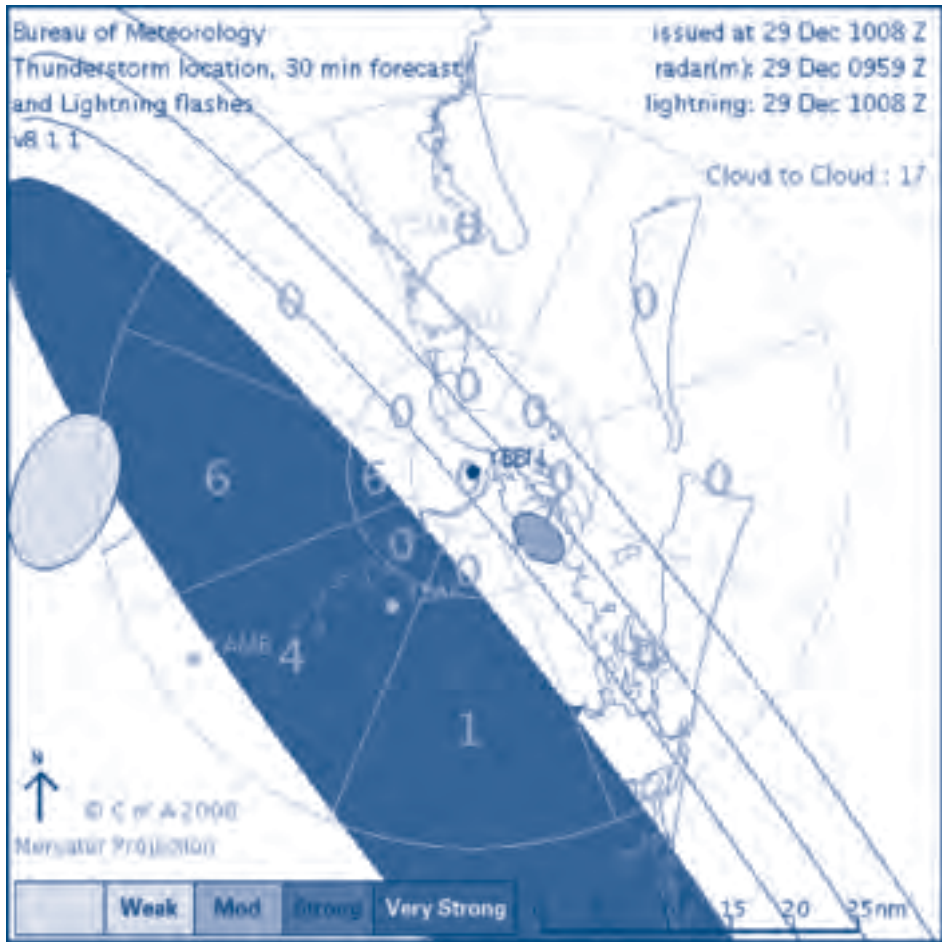


Figure 11. The Automated Thunderstorm Alert Service (ATSAS) product for Brisbane Airport on 29 December, as a thunderstorm approached the airport from the southwest. The numbers in the sectors are the number of cloud-to-ground lightning ‘flashes’ reported by the lightning sensor in the previous 10 minutes. The shading represents the intensity of the storm and is based on calculations of Vertically-Integrated Liquid. The numbers on the scale in the bottom right-hand corner are nautical miles; the range rings indicate 5, 10 and 30 nautical miles.

- Forecasting of fog at major airports was also improved via implementation of the Fog Decision Support System at Melbourne Airport and the inclusion in the system of the first version of a Bayesian network decision support component which uses statistical decision theory to give objective probabilistic guidance to forecasters on the risk of fog.
- The CP-2 polarimetric radar in southeast Queensland, which is used as a research test-bed facility, was instrumental in improving understanding of convective cloud systems in the tropics and sub-tropics. The radar enabled the study of the three-dimensional airflow during major weather events including the damaging November storm at The Gap in suburban Brisbane as demonstrated in Figure 12, which assists in explaining the origin and evolution

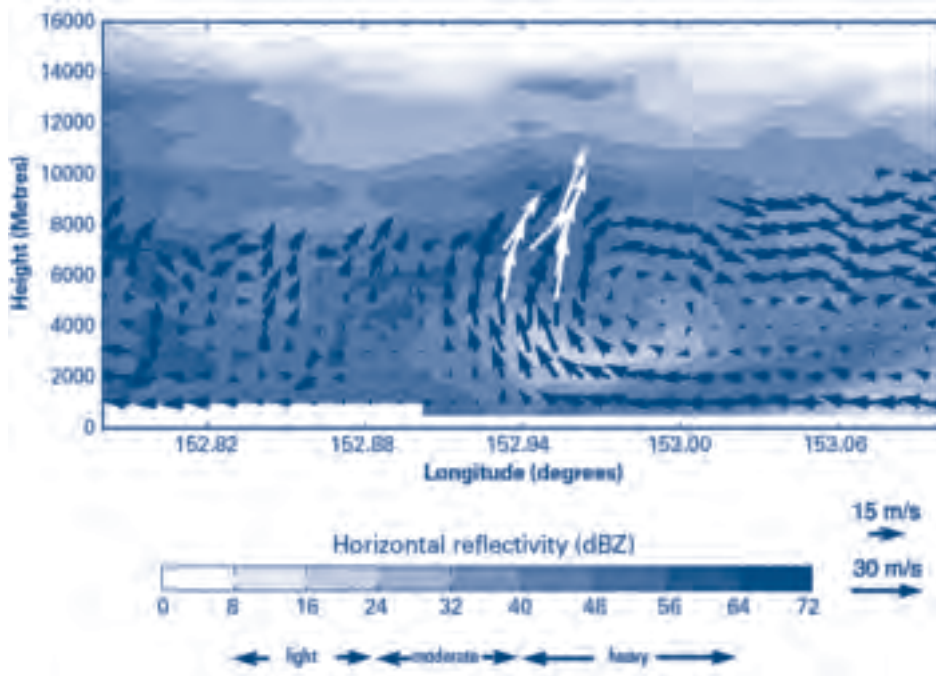


Figure 12. Severe thunderstorms affected southeast Queensland on 16 November 2008, with a destructive microburst at The Gap in suburban Brisbane. In this image from the CP2 research radar facility at Redbank Plains, the background shading shows the weather radar signal, indicating precipitation intensity, as a function of height and longitude. The overlaid arrows depict the reconstructed wind field, with the arrows in white highlighting an updraft region with wind speeds exceeding 90 km/h.

of such storms. The CP-2 facility was also a key tool in the Southeast Queensland Cloud Seeding Research Project, in which it was used for observing the evolution of raindrop size distributions within clouds. This project is a major international research field program examining the potential for precipitation enhancement by cloud seeding, funded by the Queensland Department of Environment and Resource Management, which has contracted the United States National Center for Atmospheric Research as the lead organisation for the project, and the Bureau of Meteorology to provide data and analysis assistance.

- The benefits of early work focused on refinement of the comprehensive datasets collected during the Tropical Warm Pool - International Cloud Experiment (TWP-ICE), a multi-platform field program held in early 2006, are now being realised, with large numbers of related publications appearing in the international scientific literature. The work supported by TWP-ICE data during 2008-09 included studies of the large-scale circulation in the Australian monsoon, the relative impact of aerosols and thermodynamics on convective cloud properties, and the ability of cloud models to represent these properties. This work extends knowledge of cloud physics and feeds into the improved performance of numerical weather prediction and global climate models through advances in their treatment of clouds and their influences.



- Phase 2 of the BLUElink project achieved its mid-term milestones with the development of an upgrade to the operational ocean prediction system (OceanMAPS) and continued development of the Coupled Limited Area Model (CLAM). The inclusion of additional altimetry (real-time ocean height data) obtained via remote sensing by satellites resulted in significant improvements in the accuracy of forecasts including short-term ocean 'nowcasts'. Testing of the OceanMAPS software was completed ready for use on the new supercomputer being procured by the Bureau. Improvements to CLAM tested on past tropical cyclone situations showed that the model could produce useful forecasts of tropical cyclone intensity over the first 48 hours. Planning progressed for operational trials of CLAM on the new supercomputer using the UKMO Unified Model.
- As part of the Australian contribution to the Integrated Marine Observing System (IMOS), funded through the National Collaborative Research Infrastructure Strategy, the Bureau installed hull sensors on two vessels of the Australian Voluntary Observing Fleet and three commercial ferries which are now reporting sea surface temperature (SST) observations in real-time via the Global Telecommunications System. The data are used for validation of SST analyses and ocean forecasts both within the Bureau and at other international centres (see Figure 13).



Figure 13. The Integrated Marine Observing System (IMOS) – locations of sea surface temperature and meteorological data received from ships over a 12-month period.



Figure 14. World map showing tsunami source locations used in the expanded database of tsunami scenarios developed for use in the Australian Tsunami Warning System.

- An expanded database of almost 2,000 scenarios of tsunami generation in the Pacific and Indian Ocean regions, for about 500 different tsunamigenic earthquake locations, was developed for use in the Australian Tsunami Warning System (ATWS), using the MOST (Method of Splitting Tsunami) model, developed in the United States (see Figure 14). A method was developed for determining the levels of tsunami warning (as judged by wave heights) that would be required for land and marine areas of Australia and its offshore territories under each scenario. When an earthquake occurs which may generate a tsunami, this comprehensive database of tsunami situations is used in conjunction with data obtained from sea-level monitoring equipment and deep ocean tsunameters to determine the threat level to communities and the warnings to be issued.

Research Related Activities

Scientific Publications

The publication of scientific and technical results is a vital element of research and development work in the Bureau of Meteorology. During 2008-09 more than 100 peer-reviewed papers were accepted or published in books and international journals, around 120 conference papers were delivered, and nine internally-reviewed CAWCR Technical Reports were published.

Many research staff are involved in the peer review of scientific research performed within the Bureau, in addition to acting as reviewers for work from other organisations and peer-reviewed international journals. CAWCR staff also manage the editorial office and oversaw the publication in March of the inaugural issue of the Australian Meteorological and Oceanographic Journal, a new peer-reviewed journal with a focus on southern hemisphere



atmospheric, oceanographic and related sciences, published by the Bureau in cooperation with the Australian Meteorological and Oceanographic Society. The journal is the successor to the Australian Meteorological Magazine, published by the Bureau continuously from 1952 to 2008. Scientists from CAWCR also serve on the editorial board of the Australian Meteorological and Oceanographic Journal and many other international scientific journals.

The papers for the second CAWCR Modelling Workshop, on the theme 'High Resolution Modelling', were published and distributed before the workshop in November, and are also available on the Bureau's website.

Collaboration

The Bureau is involved in two major collaborative research efforts - CAWCR and ACCESS - as well as a number of smaller joint initiatives. Many collaborative activities involve a range of partners, both within Australia and internationally.

Meteorological and oceanographic research in Australia is carried out principally by the Bureau and CSIRO through integrated Bureau/CSIRO research capability teams in CAWCR. Research is also performed by a number of university groups and, to a lesser extent, by other government departments and agencies and the private sector.

ACCESS forms the central focus of CAWCR, and as an initiative involving the Bureau, CSIRO and the university sector, it strengthens the already effective collaboration between organisations within Australia on earth system modelling. The initiative is based on a formal agreement with the UKMO allowing Australia to use their Unified Model, a high-powered computer-based climate and weather prediction program, and to adapt it for Australian conditions. This collaboration with the UKMO will allow Australia to maintain a world-class climate, weather and earth system modelling capability including mesoscale modelling over the Australian region, and enables a two-way exchange of knowledge through collaborative further development of the Unified Model itself. For example, there are plans to incorporate improvements developed in Australia, such as tropical modelling capability and an improved radiation scheme, within the Unified Model. During 2008-09 several Australian scientists once again undertook placements in the UKMO to further modelling developments. ACCESS was also the driver for collaborations with the Korea Meteorological Administration (KMA) which is developing a model system similar to ACCESS, and initial discussions about collaboration with New Zealand's National Institute of Water and Atmospheric Research. Such cooperative and collaborative efforts ultimately save resources for all parties in achieving research and development objectives.

The Bureau is a partner in long-running collaborative efforts such as the Australian Climate Change Science Program (ACCSP) which aims to improve understanding of climate variability and climate change in order to better inform industry, government and the wider community. The ACCSP is administered and funded by the Department of Climate Change and is conducted in partnership with the Bureau and CSIRO. Research in CAWCR supports the ACCSP in the areas of sea level monitoring, the study of climate processes and feedbacks, detection and attribution of climate change, improved climate modelling through the ACCESS initiative, model evaluation and prediction, regional modelling and downscaling, studies of the links between climate variability and climate change, and through improved communication.



Instrumentation on a research aircraft owned by the South African Weather Service is prepared for another mission during the South East Queensland Cloud Seeding Research Project, an international collaborative research field program.

Field programs are also an important driver for collaborative scientific research and development. CAWCR staff contributed to the South East Queensland Cloud Seeding Research Project, which encompasses both national and international collaboration, with representation from the National Center for Atmospheric Research (US), the South African Weather Service and Monash University.

While CAWCR scientists are involved in major collaborations, important work is also performed in small projects. Some examples of these smaller collaborations are a project carried out with Macquarie University on the interannual variability of ozone in the polar regions, a study with Brazilian researchers on subtropical cyclones, and a project with the Meteorological Service of Canada on improving real-time forecast verification and lightning probability forecasts. Collaborations are enhanced through outputs such as publications and seminars, many of which involve research partners. CAWCR hosts seminar series at both the Bureau and the Hobart office of CSIRO Marine and Atmospheric Research on topics of broad scientific interest, which are open to the community as well as staff and visitors. Of around 100 seminars hosted across both sites in 2008-09 (39 at the Bureau and around 60 at CSIRO), the majority were given by invited experts and collaborating scientists, with 21 delivered by CAWCR scientists.

Public presentations were also given to school groups and other members of the community at an event held by the Bureau during National Science Week, and on numerous occasions to other community groups. For example, talks on climate change mechanisms and climate change-induced alterations to ecosystems were given to groups of field naturalists



and residents' groups as part of ClimateWatch, a pilot scheme for involvement of community members in taking observations of environmental climate change impacts. The scheme was established by Earthwatch, an international not-for-profit environmental research organisation, with support from Land and Water Australia and in partnership with the Bureau of Meteorology, CSIRO and the University of Melbourne among others. Bureau staff were also involved through serving as members on panels concerned with project coordination, science and technical issues.

Cooperative Research Centres

To further improve the coordination of meteorological and related research in Australia and to provide support for the strengthening of programs in meteorology at Australian universities, the Bureau participated in multi-agency agreements for the operation of research centres in meteorology and related disciplines under the Government's Cooperative Research Centre (CRC) program. Outcomes of the work of each CRC are reported via a range of mechanisms, including annual reports for each CRC and in the peer-reviewed scientific literature, as well as a variety of other publications specific to each CRC. For example, the Bushfire CRC contributes to monthly 'background briefings' in a newsletter format entitled 'Fire Notes', which address emerging issues for fire managers. Many of these documents are available on the CRC websites. Significant research outcomes are taken into account in planning and management of Bureau operations such as fire weather forecasting and warning.

During 2008-09, the Bureau participated in:

- the CRC for Antarctic Climate and Ecosystems, with the University of Tasmania, the CSIRO, and the Australian Antarctic Division as core partners, and six other supporting partners (<http://www.acecrc.org.au/>);
- the eWater CRC at the University of Canberra with more than 40 other participants, including a range of industry, government (Federal, State and Local) and university partners (<http://www.ewatercrc.com.au/>); and
- the Bushfire CRC with 23 other core participants, including emergency and fire authorities at State and Federal levels, and Australian and New Zealand universities (<http://www.bushfirecrc.com/>).