METEOROLOGICAL AND RELATED RESEARCH

Meteorological and Related Research involves research undertaken in fulfilment of the Bureau’s responsibilities as a national research agency to contribute to the advancement of meteorological science in Australia, to develop the application of meteorology to the needs of the Australian community, and to support the Bureau’s services.

The Bureau of Meteorology Research Centre (BMRC), in collaboration with other areas of the Bureau, carries out the main research activities reported in this chapter which are implemented through four outputs: Weather Research, Climate Research, Ocean Research and Hydrology Research. The research undertaken in the BMRC is complemented by supporting research and development undertaken in the Bureau's Regional Offices and other Head Office Branches.
### PLANNED OUTCOME 2006-07

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Advancement of meteorological science and understanding of the mechanisms of Australian weather and climate.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objective</td>
<td>To advance the science of meteorology, develop an integrated, comprehensive description and scientific understanding of Australia’s weather and climate, develop the application of meteorology in the national interest and improve the operations and services of the Bureau.</td>
</tr>
</tbody>
</table>
| Effectiveness indicators | The extent to which:  
- the Bureau of Meteorology Research Centre is recognised for the quality and extent of its contribution to national and international atmospheric science;  
- progress is achieved in the characterisation and understanding of the processes which determine Australian weather and climate;  
- progress is achieved on applied research problems addressed to the Bureau or which arise in the course of its operations;  
- cost effective new applications and services emerge from Bureau research;  
- Bureau research can be shown to have contributed to improvements in the quality of its operations and services; and  
- the scientific health and morale of the Bureau are enhanced. |

### OUTPUTS 2006-07

Meteorological and Related Research comprises Output 1.2, one of the Bureau’s four output groups. Output 1.2 is delivered through four individual output areas: Weather Research, Climate Research, Ocean Research and Hydrology Research. Performance targets include original publications in the peer-reviewed scientific literature on Australian and global meteorology, hydrology, climate and climate change, and oceanography; reviews, project reports, conference presentations, and the general build-up of scientific expertise, reputation and influence in the international scientific community; published and unpublished contributions to the development and implementation of new and improved applications of meteorology; and new operational meteorological and related systems and techniques. Outputs also include effective Australian participation in international research programs directed towards improved understanding of Southern Hemisphere and Australian meteorology and oceanography.
OUTPUT PERFORMANCE 2006-07

Output performance is measured against a number of targets, including quality, quantity and price. The performance against each of these output targets during 2006-07 is provided below.

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Target</th>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of BMRC scientists invited to serve on external advisory committees etc.</td>
<td>65</td>
<td>73</td>
</tr>
<tr>
<td>Number of invitations received to present papers at external conferences and workshops</td>
<td>15+</td>
<td>31</td>
</tr>
<tr>
<td>Number of system changes, developed by the BMRC, accepted for implementation by operational units (the National Meteorological and Oceanographic Operations Centre and the National Climate Centre)</td>
<td>5</td>
<td>11</td>
</tr>
<tr>
<td>The BMRC annual report and all workshop and contract project reports produced in good time</td>
<td>reports produced on time</td>
<td>reports produced on time</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Quality</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of viable research groups focussed on priority research issues</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Number of research publications including refereed journals, articles, book chapters, conference papers and miscellaneous reports, and missions</td>
<td>110</td>
<td>167</td>
</tr>
<tr>
<td>Number of of external collaborative projects undertaken</td>
<td>75</td>
<td>78</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Price</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Weather Research</td>
<td>$6.621m</td>
<td>$6.414m</td>
</tr>
<tr>
<td>Climate Research</td>
<td>$2.661m</td>
<td>$3.271m</td>
</tr>
<tr>
<td>Ocean Research</td>
<td>$1.310m</td>
<td>$2.555m</td>
</tr>
<tr>
<td>Hydrology Research</td>
<td>$1.394m</td>
<td>$0.624m</td>
</tr>
</tbody>
</table>

Comments on output performance

Publication output, comprising refereed journal papers and book contributions, conference papers and research reports, remained above target this year, representing a tangible measure of the breadth and quality of scientific research in the Bureau. Collaborations involving BMRC scientists extend from major international activities of global importance such as assessments of the Intergovernmental Panel on Climate Change (IPCC), to small (but important) projects between individual scientists. Of particular value are international collaborations with neighbours in the Australian region. Examples include nowcasting and forecast verification support for the Beijing 2008 Olympics; the establishment of a Southern Hemisphere project to improve the predictability of high impact weather, under the umbrella of The Observing system Research and Predictability Experiment (THORPEX); mapping tropical rain-
fall in Bali with Indonesian researchers; collaboration on tsunami modelling with Indian Ocean and southwest Pacific countries; and a range of projects with Chinese researchers studying monsoon interactions, arid climate and the impact of land-use changes on weather and climate.

The measure of system changes in the Bureau’s operational systems associated with research and development activities reflects improvements in a range of forecast products. New developments and upgrades this year included the launch of the operational phase of the Australian Air Quality Forecasting System (AAQFS), the release of the first generation tsunami forecasting model, T1, and critical aviation support via improvements and upgrades in airport thunderstorm alerting systems and the volcanic ash warning system.

The standing of Bureau scientists is reflected in the number of invitations to present papers at national and international conferences, symposia and workshops.

**ACHIEVING THE OUTCOME**

Meteorological and Related Research is delivered through four individual outputs that contribute to the achievement of the desired outcome. The developments in each of these outputs during 2006-07 and their contribution to the outcome are outlined below.

**OVERVIEW OF 2006-07**

The need to develop critical mass in key research areas for Australia was a driver for negotiations between the Bureau of Meteorology and CSIRO on the formation of the Centre for Australian Weather and Climate Research (CAWCR), a joint research operation to drive progress towards world-class atmospheric, climate and earth system science research and modelling. CAWCR is expected to become formally operational early in the 2007-08 financial year.

For much of the year the number of research groups in BMRC was maintained at six - Model Development, Data Assimilation, Climate Dynamics, Weather Forecasting, Climate Forecasting and Ocean and Marine Forecasting. The Climate Dynamics and Climate Forecasting groups are the main contributors to the Climate Research output area, while the Weather Forecasting and Ocean and Marine Forecasting groups represent the main resources contributing to the Weather and Ocean Research output areas respectively. The Hydrology Research output area draws on a more distributed set of resources, with the main contribution coming from the Weather Forecasting group but with some of the relevant research and development effort located in the Bureau’s Regional Offices. The Model Development and Data Assimilation groups contribute across all output areas. Later in the year, in preparation for the transition in 2007-08 to CAWCR, Model Development and Data Assimilation were brought closer together to be managed through a single group. This group is centred on activities related to the Australian Community Climate and Earth System Simulator (ACCESS) initiative, developed through collaboration between the Bureau, CSIRO and the university sector.

Cross-cutting forums have been established for research areas that involve broader collaboration. The number of externally supported staff continues to increase, via initiatives such as Australian Greenhouse Office-supported projects, major national initiatives such as the building of a tsunami research and warning capability, and the joint BLUElink project with CSIRO and the Royal Australian Navy (RAN) on ocean prediction.

The ACCESS initiative constituted a major undertaking during 2006-07. A formal agreement
was signed with the UK Met Office to provide access to, and collaboration on, their Unified Model, which forms the heart of the ACCESS system. ACCESS developments in 2006-07 have been significant and prototype components are demonstrating considerable advances relative to the current models. Key milestones include successful implementation of the new atmospheric model and the four-dimensional variational assimilation scheme which has also been obtained from the UK Met Office.

A severe drought in many of the agricultural areas of Australia focussed attention on water and climate issues. The Predictive Ocean Atmosphere Model for Australia (POAMA) provided early warning of the demise of the El Niño and a new version shows advances in rainfall prediction skill. A number of influential papers on climate variability (e.g. on the Madden-Julian Oscillation) have been published, and a method for developing seasonal predictions of fire danger was trialled.

BMRC scientists made significant contributions to the Fourth Assessment Report of the IPCC, including at the lead author level, and in particular were involved in the development of climate change projections for the Australian region. The establishment of a National Ecological Meta Database, new results on the trend in southwest Western Australia rainfall, and improved methods for determining and delineating climate variability and change were among the highlights.

Major ocean research developments in 2006-07 included the implementation of the first generation tsunami forecasting model, and completion of the initial phase of development of a world-class ocean forecasting system for Australia as part of the BLUElink project.

WEATHER RESEARCH

The largest of the research outputs, Weather Research focuses on mesoscale meteorology research, observational system development, advanced data assimilation systems and enhanced numerical weather prediction (NWP) in support of the forecast process. A major component of Weather Research is a continuing program of field studies aimed at ensuring the Bureau remains informed of advances in observing technologies, such as radars, and at improving the understanding of atmospheric processes, such as those involved in precipitation, cloud and thunderstorm development and the representation of these processes in atmospheric models. Development of improved atmospheric models and of advanced data assimilation systems is also a key underpinning of this output.

Major developments 2006-07

- The AAQFS, developed in the BMRC, became operational on 26 June; the model output is now produced on a daily basis by the National Meteorological and Oceanographic Operations Centre (NMOC). AAQFS is the result of a joint project between the Bureau, CSIRO Marine and Atmospheric Research and the Environment Protection Authorities of Victoria, New South Wales and South Australia and provides forecasts of air quality in the large urban airsheds of Melbourne, Sydney and Adelaide.
- Final upgrades to the Bureau’s suite of global and regional NWP models were made ahead of the introduction of ACCESS. An improved version of the Global Assimilation and Prediction System (GASP) with 60 levels (increased from 33) was extensively tested in BMRC and as at the end of the year was being run daily by the NMOC prior to opera-
tional implementation. This will be followed by a new version of the Limited Area Prediction Scheme (LAPS) with 61 levels (increased from 29) which has also been extensively tested.

- A prototype numerical weather prediction model based on the the UK Met Office Unified Model and developed within the ACCESS initiative has been trialled, showing significant improvements over the current system. These derive mostly from the adoption of an advanced four-dimensional variational data assimilation system which greatly improves the initial condition of the model. A revised strategy for taking advantage of satellite data was also developed, with a view toward implementation within the new ACCESS data assimilation system.

- Nowcasting applications and associated systems supporting short-range severe weather detection and rainfall estimation were developed and implemented operationally as part of the major Radar Network and Doppler Services Upgrade Project (RNDSUP).

- BMRC installed a range of nowcasting equipment related to the forecasting of thunderstorms in Beijing as part of trials supporting the international World Meteorological Organization (WMO) Forecast Demonstration Project to be conducted in conjunction with the Beijing Olympics in 2008. The equipment included the radar display software 3DRAPIC, the Thunderstorm Interactive Forecast System (TIFS) and a prototype real time verification system.

- Significant progress was made with research and development of the Graphical Forecast Editor (GFE), originally developed in the United States, to prepare it for implementation in Australia. Projects included the development of gridded Operational Consensus Forecast (OCF) guidance, consisting of a “consensus” forecast achieved by statistical processing of the output from a range of different numerical models used by Australian and overseas research centres. Other projects related to the development of text formatters specific to Australia to allow automatic wording of forecasts, and of an initial plan for incorporation of aviation requirements.

- The Poor Man's Ensemble (PME) uses a number of numerical models to produce quick, efficient deterministic forecasts for rainfall that are more accurate on average than those produced by any of the component models. The PME system became operational during 2006-07 and is being used to produce some of the products available on the Water and The Land (WATL) page on the Bureau’s website.

- In the first of two major fire weather studies relating to the hazard of bushfires, analyses of the impact of extreme drying on bushfires were completed. In two recent wildfires in Australia, both of which led to a number of fatalities, dramatic and abrupt drying of the atmosphere occurred at around the time of maximum fire activity (Figure 15). These surface dryings were linked to the movement of bands of dry air several kilometres above the surface moving over the fire ground, and these bands can be identified using ‘water vapour channel’ satellite imagery (Figure 16). The drier the fuel, the more active the fire, and fine fuels respond to atmospheric humidity variations on timescales of around one hour. Monitoring the water vapour imagery on days when fires are already active may provide increased warning of changes in fire activity.

- Validation of the accuracy of wind change forecasts was undertaken using automated wind
change indices. Using fuzzy logic methods, a "Wind Change Range Index" (WCRI) was developed, based on the rate of change of both wind speed and direction at a point. The time of the maximum WCRI can be defined as the time of occurrence of the wind change. The method was applied to both observations from the Bureau's automatic weather stations, and to forecasts from mesoscale NWP models, and was shown to produce forecasts which compare well with those made by experienced human forecasters. The system

Figure 16. The dark band of a dry slot slants across New South Wales, captured on water vapour imagery from the GMS-5 weather satellite on 18 January 2003, the day of the Canberra bushfires. (Picture: Japan Meteorological Agency and Bureau of Meteorology)

Figure 15. Dewpoint at Canberra Airport decreases sharply early on the afternoon of 18 January 2003, before the devastating Canberra bushfires.
will next be applied to NWP forecasts from past fire weather seasons to formally document its skill at forecasting wind changes.

- Revisions to a suite of smoke guidance products produced by the Bureau and used by fire agencies, and a comprehensive web-based training module on the background and use of the smoke guidance system, both developed for Victoria for use during the Commonwealth Games, were implemented operationally for Victoria, Tasmania and Western Australia. The training module, which is based on competencies and includes the meteorological background to the system, is also available on CD.

- The Australian Thunderstorm Alert Service (ATSAS) was installed at Perth, Darwin and Alice Springs airports as part of a progressive introduction to airports around Australia. ATSAS utilises radar and lightning data to automatically generate graphical and text products that show the location and movement of thunderstorm cells and the presence of lightning near the airport.

- Building on previous scientific and technical support from BMRC for the volcanic ash warning service, an improved web-based display of output from a volcanic ash dispersion model was developed. The warnings are based on alert of an eruption, analysis of satellite data to identify and track the ash plume, and forecast guidance from the dispersion model. BMRC also coordinated an International Volcanic Ash Workshop in Rotorua, New Zealand.

- Coordination and production of the research data sets produced by the Tropical Warm Pool International Cloud Experiment (TWP-ICE), held in the Darwin area in early 2006, has continued, as well as analysis of key weather events which occurred during the experiment.

Figure 17. A forecast of daily rainfall for 8 June during the floods in the Hunter Valley (diagram on left) produced with a lead time of 60 hours by the Poor Man’s Ensemble (PME) rainfall forecast system, compared with actual rainfall recorded for the same period (diagram on right). Numbers on the diagrams indicate amount of rainfall in millimetres.
**Contribution towards outcome**

- The implementation of the AAQFS allows environmental protection agencies to provide improved advice and alerts to the communities of some of Australia’s largest cities regarding pollution and other aspects of air quality.

- The implementation of the improved GASP and LAPS NWP systems ensure that the quality of services based on numerical weather prediction models is maintained during the move to use of the UK Unified Model within ACCESS.

- ACCESS developments and new attention to the application of satellite observations have significantly improved the scientific basis of Bureau NWP systems and the prospect of provision of improved forecast and information products to the community in the future.

- RNDSUP will deliver improvements to information available in real-time for the community and better forecast and warning services through the incorporation of the high-quality radar data in Bureau forecast processes.

- The Beijing 2008 Olympics Forecast Demonstration Project is the latest in a series of similar projects which have been carried out in association with the Olympic Games in recent years (including at Sydney and Athens). The projects involve collaboration with the National Meteorological and Hydrological Services of the host country and allow leading-edge forecasting systems developed by several nations to be introduced on a trial basis, to allow feedback to be collected on their performance prior to full operational implementation.

- The OCF guidance system gives the Bureau an ability to provide automatic daily forecasts for an increased number of specific locations in the Australian region, enhancing and streamlining the forecast service and underpinning development of the GFE.

- The application of the PME method to rainfall predictions is delivering significantly enhanced forecasts of a critical element of weather information for which there is strong community demand (see Figure 17).

- Fire weather research has led to significant breakthroughs in the understanding of wind changes and humidity in relation to fire danger, and hence to improved methods for analysing and predicting wind changes and for identifying “dry slots”, which in turn enable more accurate forecast services to be provided to fire management agencies.

- The forecasting of wind changes is a vital component of the Bureau’s fire weather forecast service, due to the abrupt changes in fire behaviour that occur with a change in wind direction. The verification of such forecasts has so far been difficult as the atmospheric systems causing these wind changes display a wide range of structures. An objective method of verification will be invaluable in assessing predictions of this critical meteorological parameter.

- Improved guidance to fire management agencies on the forecast dispersion, trajectory and concentration of smoke from fires assists with the management of fuel reduction burns and hence in the minimisation of the impact of smoke on community health and safety.

- Thunderstorms and associated lightning are a particular hazard at airports, and the roll-
out of ATSAS improves the safety of airport ground crew operations during thunderstorm events.

- Volcanic ash is a significant hazard for aviation. Enhancements to the volcanic ash warning service contribute to the increased safety of airline operations in areas of known volcanic activity.
- The analysis of data from TWP-ICE, and the development of models based on those data, is improving the characterisation and understanding of clouds in the tropics.

CLIMATE RESEARCH

Climate research in BMRC is aimed at improved understanding of Australian climate, including the effects of climate change, and the development of systems to predict climate. Climate models and observations are used to improve our understanding of climate variability, change and predictability. Evaluation and diagnostic studies aim to improve the performance of these climate models. Climate research is broadly divided into three subject areas: climate prediction on intraseasonal and seasonal timescales; studies of interdecadal variability including the understanding of climate change; and impacts of climate variability and climate change on plant and animal life as well as on society and economics.

Climate research constitutes a significant part of the Meteorological and Related Research output. There are strong links to the Bureau's Climate Services output and extensive collaboration both with other national institutions and international research agencies. This climate research is carried out through collaboration with the CSIRO and the university sector and enjoys strong support within the Australian Climate Change Science Program funded by the Australian Greenhouse Office (AGO). It also benefits greatly from several other Federal and State Government initiatives such as the Western Australian Indian Ocean Climate Initiative (IOCI), the Western Australian Marine Science Institution (WAMSI), and the South East Australia Climate Initiative (SEACI).

Major developments 2006-07

- Bureau of Meteorology scientists made major contributions to the IPCC Fourth Assessment Report. In particular BMRC provided a lead author for a chapter of the Working Group I Report on the physical science of climate change, as well as several contributing authors for both Working Groups I and II. Figure 18 is taken from one of the figures from the Summary for Policymakers produced by Working Group I.
- A Bureau scientist was an author of the report on Climate Change Impacts and Adaptation produced by the Prime Minister’s Science, Engineering and Innovation Council (PMSEIC).
- A National Ecological Meta Database was established following planning carried out the previous year. The database is a web-based system designed to document existing ecological and agricultural datasets that have the potential to be used for climate change impact work and as climate proxies. In parallel with this project, analyses of Australian natural systems datasets revealed links between breeding, population and migration changes and changes in local and broader-scale climate indices, resulting in some of the first studies of their kind for Australia. The initial web system provided the capability for users to contribute to the database and a search facility was added in February.
• Research into the development of high quality datasets suitable for use in climate change studies continued. Such datasets consist of time series of data which have been adjusted to remove, as far as possible, any misleading effects due to measurement techniques. A high quality humidity dataset was completed during the year. For wind data, the work focused on surface wind-speed data and dealt with issues caused by changes in instrumentation, the use of Daylight Saving Time (DST) in some parts of Australia, and changes in the frequency of observations. For cloud datasets, the issues included changes in observing practices, such as the move in 1949 from measurement of cloud in tenths of sky covered to oktas or eighths of sky covered, changes in the network of stations where cloud is

![Figure 18](image_url)

Figure 18. Comparison of observed continental-and global-scale changes in surface temperature with results simulated by climate models. Decadal averages of observations are shown for the period 1906 to 2005 (black line) plotted against the centre of the decade and relative to the corresponding average for 1901–1950. Lines are dashed where spatial coverage is less than 50%. Light shaded bands show the 5–95% range for 19 simulations from five climate models using only the natural forcings due to solar activity and volcanoes. Darker shaded bands show the 5–95% range for 58 simulations from 14 climate models using both natural and anthropogenic forcings. (taken from Figure SPM.4 in Summary for Policymakers, ‘Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change’).
recorded, and once again issues related to the varying use of DST.

- With support from The Climate Institute, scientists from the Bureau and the Bushfire Corporate Research Centre (CRC) commenced and largely completed an investigation into the identification and explanation of changes in fire danger index over southeastern Australia in recent decades.

- Development of a mechanism for producing seasonal predictions of fire danger indices continued with the Bushfire CRC. Predictions were produced on a trial basis, for the southern portion of Australia during the summer fire season, and for northern Australia during May. Key stakeholders and Bureau operational staff then combined the available data and their expertise on fire danger to produce a consensus seasonal outlook.

- Bureau scientists had key roles in a WMO Committee on Climate Change Impacts on Tropical Cyclones which in December published a high profile expert statement on the relationship between climate change and the occurrence of tropical cyclones following a major International Workshop on Tropical Cyclones (IWTC) held in Costa Rica. Questions remain over whether the observational evidence supports the contention from the theoretical and modelling studies that climate change will lead to an increase in the frequency of tropical cyclones.

- The extension of a series of coupled climate model experiments, utilising a range of different models, produced further evidence attributing the decline in rainfall in southwestern Western Australia to anthropogenic climate change. The studies also suggested that other factors such as land clearing may have enhanced the rainfall signal. While natural variability played a role, it was insufficient to explain the extent of the decline.

- A series of modelling studies has demonstrated that the El Niño-Southern Oscillation (ENSO) phenomenon drives sub-surface ocean circulations that are predictable on the time scale of several years in advance.

- A new version of the Predictive Ocean Atmosphere Model for Australia (POAMA) dynamical seasonal prediction system was developed. A comprehensive set of “hindcasts” from 1980-2005, consisting of a 10 member ensemble each month, was completed, showing that the model is capable of reproducing past conditions with accuracy, and the system is now undergoing operational trials in real-time.

- Bureau of Meteorology scientists continue to be prominent in international developments on understanding, monitoring and predicting the large scale tropical phenomenon known as the Madden-Julian Oscillation (MJO). Recent advances include the development of a physical measure of the MJO based on environmental data and its incorporation into the output suites of a large number of international forecast models.

- Work on the MJO has resulted in improved prediction of the onset of the North Australian monsoon and prediction of tropical cyclone activity over northern Australia two weeks in advance. This work will be converted into new operational products in the next year.

- The 18th BMRC Modelling Workshop attracted the largest group of attendees yet in this long running series of international workshops. The theme for the event was The Australian Community Climate and Earth System Simulator – challenges and opportunities. Invited
speakers included eminent scientists from climate and atmospheric research centres from all over the world including the United Kingdom, Europe, the United States, New Zealand, South Africa and Japan.

**Contribution towards outcome**

- Australian participation in the IPCC contributes to the global understanding of climate change and ensures that the Australasian region receives appropriate attention in the IPCC process.
- PMSEIC is the Australian Government’s principal source of independent advice on issues in science, engineering and innovation and relevant aspects of education and training.
- The National Ecological Meta Database draws together existing but currently widely-dispersed datasets and contributes to filling a gap in the understanding of Australian climate change impacts identified by the Third Assessment Report of the IPCC in 2001.
- High-quality datasets that can be used with confidence as representative of actual meteorological conditions are critical to the effective investigation of the extent and impacts of climate change.
- Studies into the nature of the major influences on fire danger contribute to clarification of the possible impacts of climate change.
- Seasonal predictions of fire danger constitute an important strategic planning tool for all agencies involved in fire management.
- Studies of climate change impacts on natural hazards such as tropical cyclones are critical to assessments of the overall impact of such change on the global community.
- Rainfall in the southwest of Western Australia has declined by about 10 per cent over the past 30 years but the resulting streamflow has reduced by more than 50 per cent during the same period. Understanding the underlying causes of these effects is of critical importance in planning for the impacts of climate change.
- Longer lead times in the prediction of the ENSO phenomenon assist strategic planning in a range of government and industry sectors.
- Preliminary results from POAMA show significant improvement in El Niño forecast skill and potential for skillful predictions of Australian rainfall on both intra-seasonal and seasonal time scales.
- BMRC is providing world leadership in the study of tropical intra-seasonal variability and the MJO. The newly developed measure of the MJO provides a more convenient and cost-effective means of diagnosis than the spectral analysis previously required.
- Outlooks of tropical cyclone occurrence covering the next two weeks would greatly assist emergency management planning and preparation across northern Australia during the cyclone season.
- The BMRC Modelling Workshops continue to provide a productive forum for exchange of scientific ideas and findings between Australian and international scientists, to the benefit of scientific understanding in many countries.
OCEAN RESEARCH

Ocean research contributes to an improved understanding of the mechanisms underlying climate variability and the application of this knowledge to understanding, modelling and predicting the ocean and marine environment around Australia, including its use in developing and improving coupled ocean-atmosphere systems for seasonal prediction. This research involves gathering and analysing ocean and marine data, the development of sea state and ocean models, the development and application of coupled models, and collaboration in national and international initiatives. The research is focussed in the Ocean and Marine Forecasting Group of the BMRC but benefits from contributions and support from CSIRO, the Royal Australian Navy (RAN) and academia.

Major developments 2006-07

- A first-generation numerical tsunami forecasting system (termed T1) was developed and by year end was undergoing operational testing in the NMOC. The T1 system consists of 741 pre-computed scenarios produced with the MOST (Method of Splitting Tsunami) system developed by the US National Oceanic and Atmospheric Administration (NOAA) Centre for Tsunami Research. A strategy for issuing tiered tsunami warnings based on T1 within Australian Marine Forecast Zones was developed. Sample output from the model is shown at Figure 19.

- A review of the observational network design for the Australian Tsunami Warning System (ATWS) was completed and recommendations for the siting of DART™ (Deep Ocean Assessment and Reporting of Tsunami) buoys in the Tasman Sea and Coral Sea were developed. The first such buoy, in the Tasman Sea, was successfully deployed.

- A new regional high-resolution sea surface temperature (SST) analysis system was implemented after completion of testing, verification, inter-comparison and documentation, and is now running as part of routine operations in the NMOC. Products from the new system were supplied to the GODAE (Global Ocean Data Assimilation Experiment) High Resolution SST Pilot Project (GHRSSST-PP) for comparison with similar analysis products from other agencies such as the UK Met Office. This collaboration allows contributing groups to access the full set of SST measurements worldwide, which together form a very high-resolution dataset.

- Under the Integrated Marine Observing System (IMOS) initiative funded by the Australian Government’s National Collaborative Research Infrastructure Strategy (NCRIS), the Bureau was involved in a number of projects, including the “Southern Ocean Time Series” meteorological buoy located south of Tasmania, a project to equip Australian research vessels with the ability to observe atmosphere-ocean fluxes such as moisture and heat, and a project to equip vessels of the Australian Volunteer Observing Fleet with hull-mounted SST sensors.

- The new ocean analysis and prediction system OceanMAPS, developed under the BLUElink project, was successfully trialled in real-time commencing in January. OceanMAPS is based on a full Ocean General Circulation Model (OGCM) together with a data assimilation system which processes satellite observations of ocean heights, satellite-observed SST and in situ
observations including those from the global network of Argo floats (now numbering more than 2800 worldwide, each measuring ocean temperature and salinity profiles) and temperature profiles from expendable bathythermographs deployed from ships. OceanMAPS performs a seven-day forecast twice per week, with data products available on a research website utilising the OPendAP data access protocol which allows users to access those subsets of the large datasets of most interest to them. The products from OceanMAPS are expected to become available to users routinely in August 2007.

- A full reanalysis of 15 years of ocean data from the early 1990s to 2005 was performed with the results being made available to the research community via an OPendAP server.

- A regional ocean model called CLAM (Coupled Limited Area Model) was developed, with initial and boundary conditions provided by OceanMAPS. The model is being run in experimental mode over two sub-areas of the Australian region, one over the Coral Sea and one over northwestern Australia. These models will be coupled with the Bureau’s
tropical cyclone forecast system TCLAPS to investigate the impact of ocean coupling on tropical cyclone prediction.

- A collaborative ocean surface drifting buoy pilot research project was initiated between NOAA and the Bureau. Eight buoys provided by NOAA, technologically identical to those released by the Bureau operationally for collection of atmospheric data, were released at locations optimal for ocean observation purposes within the East Australian Current off the coast of Brisbane in February and March.

**Contribution towards outcome**

- The development of a first-generation numerical tsunami forecasting system represents a significant milestone in a new applied scientific area and in the development of an independent tsunami warning service for Australia.
- The DART™ buoys are essential to tsunami detection and support the operation of the tsunami warning system.
- High-resolution real-time SST are required by operational ocean and atmospheric forecasting systems for accurate modelling of the upper ocean circulation thermal structure and the exchange of energy between the ocean and the atmosphere. Australian scientists continue to play a leading role in the international experiment GODAE.
- The IMOS provides a national facility through which the ocean research community can access the ocean observation technologies required for their research projects. The use of common data formats is part of the IMOS objective.
- The successful completion of the first phase of BLUElink and operational trials mean Australia will have access to and benefit from a leading edge ocean prediction system. The BLUElink research, with CSIRO, has placed Australia at the forefront of ocean prediction science and applications.
- The reanalysis of a 15-year period of ocean data provides a reliable ocean climatology and forms a solid basis for testing the OceanMAPS model.
- It is expected that coupling of the CLAM and TCLAPS will result in better tropical cyclone prediction as a result of the improved treatment of ocean effects.
- The experimental deployment of drifting buoys specifically for ocean observation purposes will allow assessment of the value of an ongoing operational deployment program. The buoys are expected to provide useful information about convergence and divergence of ocean currents and dispersion in the ocean.

**HYDROLOGY RESEARCH**

Hydrology research within the BMRC is undertaken in support of the Bureau’s Hydrological Services output in particular and aims to improve and quantify the accuracy of estimates of mean areal rainfall over catchments, and of precipitation forecasts generated by means of NWP models or nowcasting techniques, and to improve the representation of land-surface processes within NWP models.

**Major developments 2006-07**

- In the context of serious water deficiencies across significant parts of Australia, the Bureau
convened a successful international Cloud Seeding Research Symposium in Melbourne on 7-9 May, to review the status of cloud seeding, including the scientific evidence, and assess current and future plans for cloud seeding in Australia. Researchers from CSIRO and Monash University, as well as TasHydro and Snowy Hydro participated. Several international experts, including from Japan, the US, and Israel gave keynote addresses. The symposium attracted considerable public interest and provided a focus for a new coordinated Australian research effort in precipitation enhancement.

- The new CP2 polarimetric Doppler radar facility at Redbank Plains in southeast Queensland will serve as a test facility for the use of radar in advanced quantitative precipitation estimation techniques and flash flood warning systems, and in assessing the potential for seeding of convective clouds. Site works have been completed and test data are being received from the instrument.

- Improved analyses and predictions of rainfall developed in the BMRC were made available to the public via the Bureau’s new Water and the Land (WATL) web page.

- Work on eWater CRC projects continued, including:
  - the development of a nested multi-site daily rainfall model which uses statistical techniques to generate a time series of rainfall at a number of geographical locations while retaining the known correlations between the sites;
  - the development of STEPS (Short Term Ensemble Prediction System) which blends rainfall estimates from radar nowcasting techniques with output from a high-resolution deterministic model to produce ensemble forecasts of rainfall at high spatial and temporal resolution (rainfall amounts for periods of 0-6 hours at 10-minute intervals, at 2-kilometre spatial resolution);
  - the use of STEPS rainfall forecasts to drive a rainfall-runoff model used in operational flood forecasting for the Georges River catchment in New South Wales, in order to produce ensemble forecasts of river levels; and
  - studies of the total uncertainty in hydrological forecasts stemming from all sources including the input rainfall data and the incomplete ability of the hydrological model to reproduce the real world.
• Quantitative rainfall estimation techniques based on radar estimation of rainfalls were developed and tested in preparation for implementation in the next year. The techniques take advantage of the higher-quality hardware in more modern radars and use advanced quality control to differentiate rainfall signals on radar from ground and sea clutter.

• The BMRC hosted a meeting of the International Precipitation Working Group (IPWG) during October to review progress on the quantitative detection and forecasting of precipitation from meteorological satellites. More than sixty scientists from around the globe attended. The first day of the meeting was held jointly with the two-week Asia Pacific Satellite Applications Training Seminar (APSATS) for meteorologists from Australia and the Asia Pacific region.

Contribution towards outcome

• The hosting of the Cloud Seeding Research Symposium arose through the recognition of the Bureau as an impartial and objective science-based arbiter in an area that has proved controversial. The Symposium provided a platform for a more coherent and organised scientific effort in this area.

• The CP2 radar is an important tool for investigating and understanding atmospheric processes, particularly those associated with the structure of clouds and thunderstorms and the formation of precipitation and hail.

• More accurate, up-to-date and easily accessible information on rainfall observations and predictions, as provided on the WATL web page, is of high interest and value to the community generally and to primary producers and natural resources managers in particular.

• The collaboration between researchers and the hydrological community on eWater CRC projects benefits both parties. It facilitates the transfer of research information to the hydrological community, including state and local government as well as catchment management authorities, and conversely allows researchers to learn more about what is required by that community in terms of hydrometeorological products. Individual projects have more specific benefits:
  - the generation of a time series of rainfall at a number of linked points has potential use in water resource simulation;
  - STEPS is delivering new, cost-effective approaches to measurement and prediction of rainfall and is also enabling the generation of ensemble forecasts of river levels without the need for the resources required by a high-resolution deterministic hydrological model; and
  - studies of the sensitivity of hydrological forecasts to uncertainties stemming from various sources will allow estimates of the uncertainty to be included in the forecasts and should also allow better priority-setting in regard to methods of improving the predictions.

• Use of radar for quantitative rainfall measurement benefits operational flood forecasting as well as allowing more detailed measurement of rainfall in the areas surrounding the radars.

• The collaboration between the IPWG meeting and the APSATS was very useful in providing, respectively, a strong operational focus for the scientific meeting and state-of-the-art knowledge for the participants in the training course.
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. A total of 167 publications was produced in 2006-07, including refereed journal papers, articles, book chapters, conference papers and miscellaneous reports. Some 100 papers were presented at conferences, 57 peer-reviewed papers were published in books and international journals, and 11 internally-reviewed BMRC Research Reports were published.

Research staff are continually involved in the peer review of scientific research carried out across the Bureau, in addition to acting as reviewers for work from other organisations. Staff in the BMRC operate the editorial office and oversee the publication of the Australian Meteorological Magazine (AMM), the journal on Southern Hemisphere atmospheric, ocean and related sciences published by the Bureau in cooperation with the Australian Meteorological and Oceanographic Society. Scientists from BMRC also serve on the editorial board of the AMM and other international scientific journals. A new project in collaboration with the National Meteorological Library has produced a full set of back issues of the AMM from 1952 onwards in electronic form to be made available on the AMM website.

The 2006 BMRC Modelling Workshop publication on the theme The Australian Community Climate and Earth System Simulator – challenges and opportunities was published before the workshop in November. A longstanding backlog in the publication of other BMRC Research Reports was further reduced.

COLLABORATION
The Bureau is involved in two major research collaborative efforts - the CAWCR, and ACCESS - as well as a number of smaller joint initiatives.

Meteorological research in Australia is carried out by the Bureau, the CSIRO, a number of university groups and, to a lesser extent, by other government departments and agencies and the private sector. In recent years, the Bureau and CSIRO, as the two major agencies engaged in atmospheric research, have worked closely to ensure that Bureau and CSIRO plans for atmospheric and related research are coordinated effectively, and to identify joint research activities and areas of collaboration at the project level, particularly between the BMRC and CSIRO Marine and Atmospheric Research. Planning for the development and operation of CAWCR, which will more closely link and coordinate research in the two agencies, is at an advanced stage and agreement has been reached on the main joint operation arrangements.

ACCESS will form the core of CAWCR. ACCESS, an initiative involving BMRC, CSIRO and the university sector, is further strengthening the already effective collaboration between the Bureau and CSIRO on modelling and, with the additional collaboration with the UK Met Office, will allow Australia to maintain a world-class climate, weather and earth system modelling capability. A formal agreement allowing Australian use of the UK Unified Model (UM) was concluded, and several Australian scientists undertook placements at the UK Met Office to further this development. A two-way exchange of knowledge under the
agreement is envisaged, with plans for a new radiation scheme developed at BMRC to be implemented in the Unified Model.

Smaller collaborative research initiatives in which the Bureau is involved include the contribution of BMRC to the Australian Research Council Earth Systems Science Network. Collaborative research sponsored by the AGO, principally within the Australian Climate Change Science Program, and by the Royal Australian Navy (RAN), constitutes key elements of the Meteorological and Related Research output. The ATWS involves extensive collaboration with Geoscience Australia and researchers in Indian Ocean countries, the US and Japan. The GFE project involves extensive collaboration with the Global Systems Division of the NOAA Earth System Research Laboratory as well as other parts of NOAA. Research on climate model ensembles and multi-model ensembles is being undertaken within the Asia Pacific Climate Network. The China-Australia Climate Action Partnership provides an umbrella for collaboration with China on land use and arid climates.

Even minor collaborations can have important outcomes. Examples include a study with the University of Colima, Mexico on ozone in the tropics and a project with the Samoa Meteorological Division which involves studying the impact of ENSO on Samoa rainfall and the performance of a statistical climate prediction scheme.

Collaborations are enhanced through outputs such as publications and seminars, many of which involve research partners. BMRC hosts a regular seminar series at the Bureau on topics of broad scientific interest which are open to the public as well as Bureau staff. Of the more than 75 seminars hosted in 2006-07, 22 presentations were given by BMRC scientists and the remainder by invited experts and collaborating scientists.

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 actively participated in the development of multi-agency agreements to establish new research centres in meteorology and related disciplines under the Government’s CRC program. During 2006-07, the Bureau participated in:

- the CRC for Antarctic Climate and Ecosystems with the University of Tasmania, CSIRO Marine and Atmospheric Research, and the Australian Antarctic Division as core partners, and six other supporting partners;
- the eWater CRC at the University of Canberra with more than forty other participants, including a range of industry, government (national, state and local) and university partners; and
- the Bushfire CRC with nineteen other core participants, including emergency and fire authorities at state and federal levels, and Australian and New Zealand universities.
NATIONAL RESEARCH PRIORITIES

The Bureau of Meteorology aligns with, and works to, the National Research Priorities (NRP) in a manner consistent with its statutory responsibilities under the Meteorology Act. The resources and priorities for the Research Division of the Bureau and BMRC are allocated within that context, with little freedom or discretion to tackle NRP that are not within the Bureau of Meteorology’s core mission.

The Bureau’s major contribution to the NRP relates to An Environmentally Sustainable Australia due to its close relationship to the Bureau’s functions and objectives. The NRP of Safeguarding Australia is however increasing in relative importance because of the strong collaboration with the Royal Australian Navy and the evolving role of the Bureau of Meteorology in support of national infrastructure. The implementation of ACCESS led to a re-alignment and focusing of resources and activities in Frontier Technologies as well as infrastructure.

Against An Environmentally Sustainable Australia, research in hydrology and related water issues has increased in BMRC and elsewhere in the Bureau, e.g. the National Climate Centre (climate observations and analysis) and the Hydrology Unit (water resource assessments). Significant progress has been made in understanding the relationship between rainfall deficiencies in southwest Western Australia and climate change, with new results indicating a link to greenhouse gas related climate change. Similar research is being conducted for southeast Australia in order to understand trends in that region.

BMRC provides national leadership in climate prediction research, particularly through the development and operation of the POAMA seasonal climate prediction system. The POAMA system provided early warning of the demise of the 2006-07 El Niño. The role of intraseasonal variability, including the MJO, has been a major focus within BMRC and a number of studies were completed.

The development of the National Ecological Meta Database is an example of how Bureau research has responded to an NRP even though the science is not part of the Bureau’s core mission. The availability of expertise within the Bureau, and broad experience in climate research and climate data, encouraged BMRC to take on this unique initiative.

Research projects under the Australian Climate Change Science Program (sponsored by the AGO) continue to make fundamental contributions to the knowledge and understanding of climate change. The IPCC Fourth Assessment Report was a major focus during 2006-07.

Research on climate variability and bushfires is also contributing to this priority goal.

The NRP of Promoting and Maintaining Good Health was supported through the release of the “SunSmart” UV alert system. The implementation of the AAQFS is also a significant contribution to this area.

There has been a major shift in emphasis toward the Frontier Technologies NRP, mainly because of the decision to develop ACCESS. ACCESS represents a frontier technological development for weather prediction, climate simulation and prediction, and for the emerging science of “earth systems” (land processes, atmospheric chemistry, marine chemistry, etc.). This undertaking is being led by the Bureau and CSIRO, with significant contributions from the university sector. By 2008, Australia will once again be at the leading edge of these modelling fields, thanks in part to further collaboration with the UK Met Office.
Innovative technologies are also being applied to weather forecast systems, reducing the need for human involvement in some aspects of forecast production through smart information use. The deployment of the OCF as part of this process represents groundbreaking technology internationally. The priority goal of Smart Information Use is also a focus for data and information management research, e.g. in support of aviation research and the volcanic ash warning service.

The implementation of ACCESS has also led to a strengthening of the Bureau contribution to the Safeguarding Australia NRP since ACCESS is in effect national infrastructure, critical for securing environmental values and for providing infrastructure important to defence. This infrastructure is underpinning a range of developments and applications in sectors and industries that are sensitive to the ocean and atmospheric environments and climate. The Bushfire CRC research provides one example of where these capabilities are being exploited in safeguarding Australian infrastructure and society.

The BLUElink ocean prediction project, in collaboration with the CSIRO and RAN, aligns with the priority goal of Transformational Defence Technologies. BLUElink is transforming the way RAN operates, delivering new and unique capacity to monitor and predict the ocean environment. The success of the initial four-year project led all parties to agree to a second four-year phase over 2006-2010. The initial system is now being implemented operationally.