THE CENTRE FOR AUSTRALIAN WEATHER AND CLIMATE RESEARCH

A Research Partnership
between the Australian Bureau of Meteorology and the CSIRO

LONG TERM PLAN

Version 4
Date: September 30, 2009
CONTENTS

1. Centre Vision and Motivation .................................................................................................................. 3
2. Scientific Scope of the Centre’s Research ............................................................................................ 4
3. Objectives .................................................................................................................................................. 5
4. Strategic Benefits from Formation of the Centre ................................................................................... 9
5. Resources ................................................................................................................................................ 15
6. Assessing Centre Performance ............................................................................................................... 15

Attachment 1: Scientific Stream Objectives and Deliverables .................................................................... 19
Program 1: Atmosphere-Land Observation and Assessment ..................................................................... 19
Program 2: Ocean Observation, Assessment and Prediction ..................................................................... 21
Program 3: Earth System Modelling ......................................................................................................... 23
Program 4: Weather and Environmental Prediction .................................................................................. 25
Program 5: Climate Variability & Change ................................................................................................. 27
Table of Acronyms ...................................................................................................................................... 29
1. CENTRE VISION AND MOTIVATION

The five-year Vision of the Centre for Australian Weather and Climate Research, 2007-12, is:

**TO BE A JOINT CENTRE FOR WEATHER, CLIMATE & EARTH SYSTEMS SCIENCE RECOGNISED FOR ITS INNOVATION AND SCIENTIFIC EXCELLENCE NATIONALLY AND AS A WORLD LEADER IN ITS FIELD.**

This Vision will be realised by combining relevant research expertise of the Commonwealth Scientific and Industrial Research Organisation (CSIRO) Marine and Atmospheric Research with the Australian Bureau of Meteorology’s (the Bureau) Research and Development capacities. The Centre will deliver critical research mass to underpin national benefit in areas judged to be central to Australia’s future, such as weather prediction, hazard prediction and warnings, ocean prediction, climate variability and climate change, responses to weather and climate related health hazards, water supply and management, and adaptation to climate impacts. This decision represents a joint commitment to working cooperatively on scientific issues of national relevance and to work together with other research groups in Australia (particularly in the university sector) and with counterparts overseas.

The Strategic Science Plan (this document) focuses on the scientific rationale and broad objectives of the Centre and provides an overview of the scientific approach that will be required to deliver against these objectives. It outlines the organisational structure for the science and leadership roles and identifies the core (on-going, long-term) and project-based (fixed-term, specified tasks) contributions to the scientific program. These contributions mainly are based on existing commitments and planned activities but also indicate some new endeavours that derive from the joint capacity of the strategic collaboration.

Key to the VISION is recognition that the leading edge of meteorological, climate, oceanographic and hydrological research jointly required by the Bureau and CSIRO to deliver national benefit requires the construction of a broader, multi-disciplinary framework known as “earth systems science”.¹

**AUSTRALIA HAS A UNIQUE EXPOSURE TO THE RISKS OF CLIMATE CHANGE AND YEAR-TO-YEAR CLIMATE VARIABILITY. THIS EXPOSURE AND ATTENDANT VULNERABILITY REQUIRE A NATIONAL SCIENTIFIC RESPONSE THAT CAN BE DELIVERED ONLY THROUGH A SOLID PARTNERSHIP BETWEEN THE BUREAU OF METEOROLOGY AND CSIRO.**

---

¹ The term “earth systems science” (ESS) is used in a variety of ways in the scientific community, sometimes to indicate a broadening of the science from the traditional physical science (atmosphere, ocean, etc.), but on other occasions to refer to multi-disciplinary scientific endeavours (see for example the Earth Systems Science Partnership). In this case ESS concerns the description and understanding of the complex interactions between the atmosphere, ocean, cryosphere, hydrosphere and biosphere, in some cases also including specifically human demographic and economic components. An integrated approach to observations and data assimilation and models is implied – so-called earth system models.
2. **SCIENTIFIC SCOPE OF THE CENTRE’S RESEARCH**

The scope of the Centre’s research is summarised in Table 1 below, which also shows the Research Program with lead capabilities in the relevant field of research.

The Centre is focused within this broad scope on scientific research relevant to immediate decision-making, such as emergency response, through to longer term timescales relevant to strategic planning and public policy. The delivery of services underpinned by Centre Research mainly will be through output focused activities in the Bureau (e.g., Weather Services, National Climate Centre) and CSIRO (e.g., Climate Adaptation, Wealth from Oceans, and Water for a Healthy Country Flagships).

Table 1. Scope of the Centre’s research capability and primary program responsibilities.

<table>
<thead>
<tr>
<th>Primary Research Field</th>
<th>Main Research Program</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Numerical Weather Prediction</td>
<td>• Weather and Environment Prediction</td>
</tr>
<tr>
<td>• Meso-scale applications</td>
<td></td>
</tr>
<tr>
<td>• Air quality prediction</td>
<td></td>
</tr>
<tr>
<td>• High Impact Weather</td>
<td></td>
</tr>
<tr>
<td>• Radar applications</td>
<td></td>
</tr>
<tr>
<td>• Forecast systems</td>
<td></td>
</tr>
<tr>
<td>• Atmospheric chemistry measurement &amp; prediction</td>
<td>• Atmosphere-Land Observation and Assessment</td>
</tr>
<tr>
<td>• Atmospheric gases and aerosols measurement</td>
<td></td>
</tr>
<tr>
<td>• Observations underpinning weather prediction</td>
<td></td>
</tr>
<tr>
<td>• Continental-scale biogeochemistry</td>
<td></td>
</tr>
<tr>
<td>• Micrometeorology</td>
<td></td>
</tr>
<tr>
<td>• Remote sensing</td>
<td></td>
</tr>
<tr>
<td>• Radar facilities</td>
<td></td>
</tr>
<tr>
<td>• Observing system research and development</td>
<td>• Ocean Observation, Assessment and Prediction</td>
</tr>
<tr>
<td>• Broad-scale ocean dynamics and processes</td>
<td></td>
</tr>
<tr>
<td>• Ocean and marine prediction &amp; forecasting</td>
<td></td>
</tr>
<tr>
<td>• Ocean carbon cycle processes</td>
<td></td>
</tr>
<tr>
<td>• Ocean climate observation</td>
<td></td>
</tr>
<tr>
<td>• Ocean remote sensing</td>
<td></td>
</tr>
<tr>
<td>• Integrated assessment of earth system dynamics</td>
<td>• Earth System Modelling</td>
</tr>
<tr>
<td>• Climate &amp; Earth system model development</td>
<td></td>
</tr>
<tr>
<td>• Land-surface &amp; carbon cycle modelling</td>
<td></td>
</tr>
<tr>
<td>• Numerical Weather Prediction</td>
<td></td>
</tr>
<tr>
<td>• Model systems infrastructure</td>
<td></td>
</tr>
<tr>
<td>• Complex systems science</td>
<td></td>
</tr>
<tr>
<td>• Forecast systems</td>
<td></td>
</tr>
<tr>
<td>• Data Assimilation</td>
<td></td>
</tr>
<tr>
<td>• Analysis of climate variability &amp; climate processes</td>
<td>• Climate Variability and Change</td>
</tr>
<tr>
<td>• Climate change risk and adaptation assessment</td>
<td></td>
</tr>
<tr>
<td>• Seasonal-to-interannual climate prediction</td>
<td></td>
</tr>
<tr>
<td>• Analysis of climate change and attribution</td>
<td></td>
</tr>
<tr>
<td>• Sea level rise &amp; coastal impacts</td>
<td></td>
</tr>
<tr>
<td>• Climate change prediction</td>
<td></td>
</tr>
</tbody>
</table>

---

2 This scope has been agreed by the centre’s participants and is included as part of the Joint Research Operation Agreement. Under Annexure B
3. OBJECTIVES

The Centre does research of high social, economic and environmental relevance to Australian governments, industry and society.

Figure 1 shows the relationship between the science of the Centre and examples of associated applications. The role of modelling as an integrative focus is clear, as is the diversity in national needs reflected through the applications.

---

**Figure 1.** Functional role of the Centre

The Centre is arranged into five Research Programs, each focussing on a core capability. Each of these programs will lead the delivery of specific research outputs within this Science plan, although many of the outputs will require inputs from more than one of the programs. *Interactivity among groups within and beyond the Centre in the creation of outputs is a key aspect of this Science Plan.* Nonetheless, each of the Programs is able to identify its core contributions to the Science Plan and these are outlined in Appendix 1.

CENTRE-WIDE OBJECTIVES

The Centre-wide objectives provide three points of focus where rapid advances need to be made during the first few years of the Centre to achieve the vision of excellence, innovation and leadership:

- Earth system science;
- Enhanced Australian earth system observation and data assimilation capability; and
- Water in the earth system.

Encapsulating these major areas of science will require effort from across the Centre.
Earth System Science

The Challenges

The science is clear. Australia will continue to be exposed to severe weather hazards and anthropogenic climate change increasingly will affect Australia for at least the next few decades. Australia’s society and economy will need to adapt to these changes. The scientific community has unleashed questions and challenges that no single institution has the capability or capacity to answer. Increasingly there is acceptance that there is no longer a clear delineation between weather forecasting, responses to extreme event, climate prediction, or ocean prediction. Australia has articulated its need for coherent earth system science capability in the National Framework for Climate Change Science. The Challenges facing us require seamless and comprehensive prediction and analysis capabilities across multiple scales of time and space and incorporating all major features of the Earth System. The need to include explicitly human-originated processes within earth system modelling frameworks also will emerge strongly throughout the lifetime of this Plan.

The Centre’s Approach

The Centre is leading the development of a state-of-the-art weather, climate, ocean, and earth system modelling capability to improve the Australian scientific community’s ability to understand and predict the role that weather and climate play in our society and its environment. In so doing, the Centre, through its partnership with service and output groups in the Bureau and CSIRO, will provide to government, industry and society in general the knowledge and tools for better dealing with the impacts of weather, climate and related phenomena. The sensitivity of natural and human-built systems to variation and change in the environment and climate is well recognized. The Centre will play a leading role in responding to these sensitivities by delivering the underpinning research necessary to inform policy and for relevant operational and research services that deliver national benefit.

National and international science initiatives increasingly are addressing explicitly the interactions between socio-economic processes and non-human Earth processes. Partnership with key stakeholders is central to these endeavours, for example in health, agriculture and infrastructure development. The Centre will embrace social and economic research into assessments of impacts of climate variability and climate change and other areas where CSIRO and the Bureau working jointly agree that such demand exists and is within the scope of the Centre.

The Centre will foster and embrace contributions to earth system model development from Australia’s universities and will work with international groups to provide for Australia world best practice earth system science capability.

The Earth System Simulation Goal
To lead the Australian science community in the development of a world-competitive Australian Community Climate and Earth System Simulator (ACCESS) and establishment of national comprehensive Earth system science capability.

Australian earth system observation and data assimilation capability

The Challenges

The world’s climate system and Australia’s climate is changing at an ever-increasing pace. The application of new science and emerging technologies provides the prospect of watching the real-time transformation of Australia’s environment. Recent advances in the acquisition and deployment of advanced in-situ observation technologies (e.g., through the Integrated Marine Observing System and Terrestrial Environment Research Network, Met RaDaR) that supplement satellite remote sensing facilities are making tangible the prospect of system-wide, near-real-time observation deliver to weather, ocean, and climate modelling systems. We can use such observations to reduce significantly the risks associated with the impacts of otherwise unanticipated or poorly anticipated changes in the earth system. The combination of leading edge earth simulation with near real time observations will enable the Centre and its output delivery partners to provide improved information to policy-makers who are developing options for mitigating the magnitude of climate change and adapting to changes that are now inevitable.
We are now confident that improved predictability and reduction of key uncertainties in the science of prediction will be achieved through better use of observation data streams within earth system models. The key challenges lie in adapting new technologies to improve the rate, quality and coverage of observations, building on and integrating existing observing systems across land, atmosphere and ocean domains, sustaining them for the benefit of the community, and ensuring that these systems deliver the information of greatest benefit.

**The Centre’s Approach**

The Centre’s structure argues for the under-pinning role for observations research (including remote sensing satellites, radar, and ocean instruments) and the need to understand the key processes that drive changes in the earth system. Three core purposes for observing capabilities underpin the Centre’s approach:

1. Tracking rapid changes in Australia’s earth system in near-real-time as part of an early warning and hazard response information system.
2. Model-data fusion for: (i) initialising model forecasts and predictions; (ii) evaluating, verifying and improving the performance of models; and (iii) calibrating parameters within prediction models.
3. Deepening understanding of the processes that are driving changes in the earth system, especially over inter-annual and centennial periods.

Building an earth system science Centre requires science to move us beyond short-term meteorological observations to earth system observations. Earth system observations integrate across: (i) different parts of the earth system (atmosphere, oceans, cryosphere, and land surface); (ii) technology platforms (including remote sensing satellites and *in-situ* platforms such as new generation weather radars and Argo floats); and (iii) data and information processing systems. We will seek to improve significantly the ability of the science community to deliver more usable information to decision-makers as part of this integration.

Most significantly, the science of the Centre must consider how to migrate the strategic science we do into **sustainable operational systems** to meet future needs.

<table>
<thead>
<tr>
<th>The Australian Earth System Observation Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>To transform the Centre’s current observational science into a comprehensive, integrated information system that delivers benefit to Australian decision makers.</td>
</tr>
</tbody>
</table>

**Water in the Earth System**

**The Challenge**

Australia is a water-driven continent. Much attention is being given to Australia’s water security, to reforming institutional arrangements for water management and use, and to identifying the ways in which water can be allocated better. All use of water exists in the context of the water cycle, however, and adequate water management rests on understanding the water cycle. Planning water use around the delivery of water through precipitation, losses through evaporation, and the uncertainties introduced as a result of climate variability and overlying climate change remains a major challenge for Australia.

The Bureau of Meteorology has been tasked by the Government to produce a water information system for the nation. This system requires the Bureau to:

1. Set standards for water data measurement and transmission;
2. Gather water information and make it freely available via the world wide web, with value-added analyses;
3. Complete annual national water resource assessments;
4. Produce an annual national water account; and
5. Provide continuously updated water availability forecasts, including flood forecasting services.

CSIRO’s Water for a Healthy Country Flagship has the goal of achieving a tenfold increase in the economic, social and environmental benefits from water by 2025.

CSIRO and the Bureau also have recognised the importance of practical solutions that will help Australia adapt to climate change. In many cases strategies for adaptation to climate change will depend on future availability of water. CSIRO and the Bureau have formalised this recognition in the formation of the Water
Information Research and Development Alliance (WIRADA) “to deliver the research and development to underpin the Bureaus’ operational water information system for Australia”.3

Much of the Centre’s science underpins these initiatives, tackling the strategic research necessary to support the delivery of operational national benefits to water management. A portfolio of research existing prior to the establishment of the Centre reveals the centrality of the water cycle in many activities. For example, recent analyses such as those undertaken to assess the sustainable water yields from the Murray-Darling Basin and Tasmanian catchments have highlighted the importance of reducing uncertainties due to the highly variable nature of the earth system and overlying human-driven perturbations. These uncertainties are characterised through the call for ‘better’ climate change projections and assessments of the likely consequences of changing climate for water availability.

The scientific challenge is to better understand the water cycle as it affects Australia, particularly the phenomena that regulate the delivery of water across the continent (see Figure 2). We need to know and understand which parts of the earth system are predictable, we need to develop systems that can forecast the predictable elements, and we need to continue to improve our forecasting to reduce the effects of irregular water supply and damages associated with severe storms.

Figure 2: A summary of the key processes that govern precipitation across the Australian continent

The Centre’s Approach

Science related to the water cycle is undertaken throughout the Centre. Our intention is to provide seamless integration of understanding of the factors influencing the hydrologic cycle, crossing time-scales from the very short such as nowcasting precipitation using radar to understanding phenomena such as the El Niño – Southern Oscillation and Indian Ocean Dipole which drive inter-annual variations in Australian rainfall, through to exploring the implications of climate change on future patterns of precipitation. The breadth of the science required means it is not feasible for a single Research Program to be mandated with addressing water research. The water cycle is fundamental to the investigations undertaken across the Centre and increasingly in collaboration with work done through WIRADA. Thus our research portfolio will be considered against the following goal.

The Centre’s Water Cycle Goal

“To advance scientific knowledge of the major drivers of Australia’s water cycle and their predictability, characterise and, where possible, reduce prediction uncertainty based on this knowledge, and deliver the strategic science to underpin strategies for managing water use across the nation.”

RESEARCH PROGRAM OBJECTIVES

Each Research Program has an overarching objective for its activities but is important to recognise the high level of interactivity and interdependence among the Programs. For example, all programs contribute in some way to the development of ACCESS, with the observation focussed programs strategically informing ACCESS data assimilation as new observational platforms and approaches (including the development of new sensors) are created and weather forecasting and climate programs developing different applications of the ACCESS system. Likewise ACCESS modelling will be used to assist in the optimal design of observational networks and will underpin much of the applications-focussed work in areas ranging from numerical weather prediction to long term climate projections.

The Research Programs have the following guiding objectives.

1. **Atmosphere – Land Observation and Analysis**
   To develop the techniques and knowledge to monitor, observe and understand atmospheric and land processes, their interaction, and the roles they play in Australia’s environment.

2. **Ocean Observation, Assessment and Prediction**
   To observe, monitor and understand the key processes that drive variability and change in Australia’s regional ocean waters and apply that understanding to model and predict the behaviours of the oceans of the Australian region and their role in regional and global climate.

3. **Earth System Modelling**
   To lead development of a world-competitive coupled climate and earth system simulation and modelling system for the Australian community.

4. **Weather and Environmental Prediction**
   To improve understanding of atmospheric processes and develop and apply numerical weather prediction systems for advanced weather forecasting and related environmental services including prediction and monitoring of severe weather and air pollution hazards and generation of climate projections.

5. **Climate Variability and Change**
   To provide predictions of future Australian climate from seasonal to century scales and deliver climate information to inform policy for managing Australia’s environmental resources, climate dependent industries, and climate change mitigation and adaptation strategies.

4. **STRATEGIC BENEFITS FROM FORMATION OF THE CENTRE**

A key expected benefit from the Centre is an increase in international scientific competitiveness for both the Bureau and CSIRO as a result of jointly bringing critical mass to Australian earth system research. Consequential benefits from this position will include:

- Improved ability to deliver science and technological solutions to the Australian governments, community, and industries, including opportunities for effective commercialisation of new technologies;
- Synergies between research in the Bureau and CSIRO that improve the operational services provided by the Bureau of Meteorology and research outputs through CSIRO National Research Flagships.

Alignment with National Research Priorities

The Centre will enhance substantially Australia’s capacity to further its National Research Priorities in two priority areas: An Environmentally Sustainable Australia - transforming the way we use our land, water, mineral and energy resources through a better understanding of environmental systems and using new technologies; and Safeguarding Australia, Transformational Defence Technologies - transforming military operations for the defence of Australia by providing superior technologies, better information and improved ways of operation. Most (approximately 90%) of the outcomes will contribute to environmental sustainability. The Centre also will deliver through the 2009 Super Science Initiative in Marine and Climate Science, delivering much of the research capacity to leverage benefit from the major Super Science infrastructure to be delivered over 2009-12.
The Centre’s research program will directly address this priority through the over-arching goal:

“To advance scientific knowledge of Australia’s water cycle and its predictability, characterise and, where possible, reduce prediction uncertainty based on this knowledge, and deliver the strategic science to underpin strategies for managing water use across the nation.”

In practice, this means: (i) better characterizing the nature of Australia’s variable climate and its role in Australia’s water cycle; (ii) identifying key drivers of these natural variations; (iii) determining the extent to which these drivers are predictable and can be predicted in climate models; (iv) implementing this knowledge to improve weather and climate predictions from immediate to seasonal scales; and (v) working with other organisations such as WIRADA, the Bureau’s Water Division, and CSIRO’s Water for a Healthy Country Flagship to help them deliver tactical and strategic water management services to the nation.

Research relevant to ‘climate and water’ will be provided from each of the Centre’s Research Programs. For example, joint projects between CSIRO and the Bureau such as the South East Australia Climate Initiative are directed towards improved characterization of the base climate and water status of the Murray-Darling Basin and surrounding regions, including identifying whether there have been major, persistent discontinuities in rainfall across the basin and whether they can be attributed to either natural variation or human-induced changes.

The development of ACCESS and other water-cycle research capability in the Centre have the potential to deliver significant impact to different aspects of water management across Australia, in collaboration with other water-focussed research and development entities and service providers. Flood forecasting and flood risk management are significant operational responsibilities of the Bureau. ACCESS will provide a consistent, robust, physically-based approach to integrating climate-system data and forecasts with the hydrologic and land-surface modelling that is the current basis of flood forecasting. Improved climate outputs linked with reliable estimates of run-off and flow into catchments from hydrologic modelling will enhance initiatives for managing national water resources that are under increasing stress.

Meeting the challenges posed by climate change and climate variability is a major motivator for the establishment of the Centre. The Centre will deliver a national capability to simulate the changes in climate brought about by human activities as well as natural climate variability at regional scales. The Centre will work to detect changes in Australia’s climate, attribute the causes of these changes, and assess their impacts and consequences across terrestrial and marine environments. These activities will be linked where appropriate with the operations of the Bureau to deliver improved climate services for the nation and with research into effective climate adaptation strategies being led by the CSIRO Climate Adaptation Flagship.
The Climate Variability and Change, Atmosphere-Land Observation and Assessment, and Ocean Observation, Assessment and Prediction Programs within the Centre together will address the detection and attribution of climate changes as they occur. The Earth system modelling capability developed through the Earth System Modelling Program will allow the Centre to provide improved projections of climate change, addressing a greater number of variables of importance to responding to climate change across Australia (e.g., humidity, evaporation, rainfall, wind, sea-levels, sea surface temperatures, changes in the frequencies of extremes). The development of approaches to downscaling the outputs from earth system models and application to forecasting services tackled through the Weather and Environmental Prediction Program will deliver information at scales where Australian live, work and respond to their environment. The Centre will also provide an interface between the underpinning science of climate change and the wider community of natural scientists, social scientists and analysts who are critical to the development of robust mitigation and adaptation strategies for the nation.

SAFEGUARDING AUSTRALIA
TRANSFORMATIONAL DEFENCE TECHNOLOGIES

Transform military operations for the defence of Australia by providing superior technologies, better information and improved ways of operation.

Australia has a small defence force to protect a large continent and a substantial maritime region of responsibility. Its operational advantage has been maintained through a superior capability which is dependent on leveraging innovative technologies. Although some benefits can be gained from overseas research, Australia has to conduct its own research to address uniquely Australian demands. A systems approach which harnesses the research capabilities of all stakeholders is essential to the successful development and introduction of innovative technologies.

The Centre will deliver to this goal wherever Earth system science intersects with defence technologies. Specifically, the partners are committed to continued development of the BLUElink project to create a model that can simulate at high resolution the unique Australian ocean dynamics, and, later global ocean dynamics, within which our Navy and merchant fleets and marine industries must operate. The collective efforts of the Centre’s Ocean Observation, Assessment and Prediction, Coupled Earth System Modelling, and Climate Variability and Change Programs will demonstrate how Earth system science within a joint research operation can contribute to Safeguarding Australia.

THE RESEARCH PORTFOLIO OF THE CENTRE IS AlIGNED CLOSELY WITH THREE OF AUSTRALIA’S NATIONAL RESEARCH PRIORITy GOALS AND WILL LEVERAGE SUPER SCIENCE INITIATIVE INFRASTRUCTURE TO REALISE SIGNIFICANT CAPABILITY ENHANCEMENTS THAT DELIVER RESEARCH OF NATIONAL BENEFIT AND GLOBAL IMPACT.

Partner Benefits

Table 2. Summary of benefits obtained by the Bureau, CSIRO and the nation through bringing together their relevant research capabilities

<table>
<thead>
<tr>
<th>Benefits to CSIRO</th>
<th>Benefits to the Bureau of Meteorology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Opportunity to develop a more robust climate &amp; Earth system modelling platform and infrastructure.</td>
<td>Additional scientific expertise and capability provided to core service areas.</td>
</tr>
<tr>
<td>Greater impact of CSIRO research through shorter delivery pathways and enhanced opportunity for operational adoption of CSIRO innovations, specifically to Bureau operational services and systems.</td>
<td>Broader scientific knowledge to underpin Bureau operations.</td>
</tr>
<tr>
<td>Improved access to Bureau science infrastructure, expertise and data.</td>
<td>Highly visible presence in key new areas such as Earth system science.</td>
</tr>
<tr>
<td></td>
<td>Improved sustainability of research effort.</td>
</tr>
<tr>
<td></td>
<td>Enhanced observational research relevant to Bureau services.</td>
</tr>
</tbody>
</table>
- Sustainable operation of the Cape Grim Atmospheric Observation facility
- Added depth and expertise for development of weather and climate modelling capability.

<table>
<thead>
<tr>
<th>Joint Benefit to CSIRO and Bureau</th>
<th>National Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scientific critical mass in key national research priority areas that are fundamental to the missions of CSIRO and the Bureau.</td>
<td>More effective and efficient use of public funds for weather, climate and Earth system research in Australia.</td>
</tr>
<tr>
<td>Shared ability to maintain and evolve crucial systems and applications in weather, climate and related areas at levels consistent with policy demands in Australia and internationally.</td>
<td>Improved delivery in key research priority areas of: climate, water and specific applications related to national security.</td>
</tr>
<tr>
<td>Development of an Earth system research capability that has the size and intellectual capacity to address the major scientific challenges that neither partner can tackle independently.</td>
<td>Enhanced ability to respond to national requirements in relevant application areas, including climate impacts and national weather applications.</td>
</tr>
<tr>
<td>Resolution of long-standing issues of potential duplication or competition between the Bureau and CSIRO.</td>
<td>Significant enhancement of Australia’s capacity to analyse and apply diverse observations of the ocean, land surface, and atmosphere to underpin national and regional environmental, social and economic responses to climate variability and climate change.</td>
</tr>
<tr>
<td>Major opportunities in the area of remote sensing technologies as applied to earth system science in which both CSIRO and the Bureau alone lack critical mass.</td>
<td>Enhanced support for Australia’s strategic engagement in international fora underpinned by excellence in weather, climate, and Earth system research.</td>
</tr>
<tr>
<td>Enhanced international reputation and visibility in Earth system research.</td>
<td></td>
</tr>
</tbody>
</table>

CENTRE RELATIONSHIPS WITH PARENT ORGANISATIONS

Strategic Alignments

The Centre operates within a complex matrix organisational structure. The Centre is seen by CSIRO primarily as a home of capability delivering research capacity to the needs of major national research and development delivery vehicles such as National Research Flagships and Research Output Themes. The Bureau, however, expects the Centre to deliver science outcomes directly to support the Bureaus operational functions.

BUREAU

The Centre delivers research outputs to the Bureau through the Bureau’s Research Support Program, which has the objective:

*To advance scientific knowledge of weather, climate, oceanography and hydrology, with a focus on the development and application of a world-competitive coupled climate and earth system simulator and associated systems to meet the current and future system and service research needs of the Bureau in delivering national benefits to Australia.*

CSIRO

A key CSIRO objective over the period of this Plan is to:

*Boost science capability to achieve more effective science and technology solutions for the Australian community, industry and the environment through targeted partnering, alliances and ventures.*

The Centre is key to boosting national science capability in the climate and ocean science domains. The Centre’s primary capabilities are delivered to the Climate domain, which is seeking “Practical solutions to help Australia adapt to climate change” through support for major research themes in CSIRO Marine and Atmospheric Research and the Climate Adaptation, Water for a Healthy Country, and Wealth from Oceans National Research Flagships. Centre capability also produces knowledge, information tools and other research outputs that underpin research and development in other domains, particularly water, agricultural sustainability, and sustainable energy systems. Capability managed through the Centre sometimes delivers
outputs outside the Scope of this Plan to domains such as energy, especially through insights into the sustainability of energy technologies that depend on or affect weather and climate or marine systems.

Operational interfaces

Developing robust relationships with primary Bureau Programs, the Bureau’s regional offices, and the CSIRO’s Flagships and core research Themes is central to the operation and success of the Centre. Figure 3 shows schematically some of the key relationships into other parts of CSIRO and the Bureau.

Figure 3. Schematic of some of the key ‘internal’ interfaces.

Specific long-term research outputs are outlined in more detail in the Research Program Plans appended to this document, whilst detailed description of research outputs is properly left for articulation in annual work plans. The following table provides an overview of some major outputs from the Centre in its first five years.

Table 3. Major research outputs associated with the identified research fields of the Centre.

<table>
<thead>
<tr>
<th>RESEARCH FIELD</th>
<th>KEY RESEARCH OUTPUTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>* Atmosphere– Land Observation and Analysis</td>
<td></td>
</tr>
<tr>
<td>Atmospheric Chemistry Measurement and Prediction</td>
<td>Experimental data products for model-data fusion and applications including: environmental monitoring, ocean monitoring and assessments, water availability assessments</td>
</tr>
<tr>
<td>Observing system research and development</td>
<td>New methods for assimilating earth observation data into models for the purposes of: (i) initialisation, (ii) validation and (iii) observational reanalysis (common to several Programs)</td>
</tr>
<tr>
<td><strong>Ocean Observation, Assessment and Prediction</strong></td>
<td></td>
</tr>
<tr>
<td>-----------------------------------------------</td>
<td></td>
</tr>
<tr>
<td><strong>Ocean Climate Observation</strong></td>
<td>An integrated ‘blue water’ marine observing system for ocean climate, as part of an Integrated Marine Observing System for Australia</td>
</tr>
<tr>
<td><strong>Ocean forecasting</strong></td>
<td>A world class ocean forecasting system for the Royal Australian Navy and the Australian ocean community</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Earth System Modelling</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Numerical weather prediction systems</strong></td>
</tr>
<tr>
<td><strong>Coupled climate and earth systems modelling</strong></td>
</tr>
<tr>
<td><strong>Modelling tools to provide local scale climate projection information</strong></td>
</tr>
<tr>
<td><strong>Integrated assessment of human interactions with the environment, weather and climate systems</strong></td>
</tr>
<tr>
<td><strong>Simulation infrastructure</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Weather and Environmental Prediction</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Forecast systems</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Aviation forecasting</strong></td>
</tr>
<tr>
<td><strong>Environmental forecasting (includes air quality and atmospheric exposure forecasts, bushfire weather and associated air quality impact assessments)</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Climate Variability and Change</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Seasonal to inter-annual climate prediction</strong></td>
</tr>
<tr>
<td><strong>Analysis of climate variability</strong></td>
</tr>
<tr>
<td><strong>Climate change prediction</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Climate change attribution</td>
</tr>
<tr>
<td>----------------------------</td>
</tr>
<tr>
<td>Climate change impacts</td>
</tr>
</tbody>
</table>

5. **RESOURCES**

The Centre comprises resources contributed ‘in-kind’ by the Bureau and CSIRO. The primary resources formally allocated to the Centre are the research personnel that comprise core Centre capability and that are charged with delivering the research objectives of the Centre, its partners and collaborators.

The Bureau and CSIRO expect to each contribute approximately 50% of the research capability available through the Centre, though it is acknowledged that the actual balance of contributions will vary from time to time and is not expected to remain exactly at 50:50. The Centre Supervisory Committee is charged with assessing periodically whether imbalance in partner contributions is of concern to the partners or indicative of Centre malfunction.

There were approximately 250 researchers assigned to the Centre at its foundation. It was expected that the resources of the centre would grow as the value and standing of the Centre was recognised by the partners and the research and development collaborators and users of Centre capability. The number of contributed researchers had grown to over 300 at June 2009.

The Bureau and CSIRO each recognise that considerable institutional support is required to maintain research and development capability. Such support is to be provided by the partners consistent with existing institutional practice to support the research staff they each contribute to the Centre and no attempt will be made to account formally for the value of those support services. Similarly, the infrastructure and facilities available from the Bureau and CSIRO will be provide in good faith in the spirit of cooperation to enable the Centre to complete its activities without attempt to compare the value of such contribution.

6. **ASSESSING CENTRE PERFORMANCE**

The performance of the Centre will fit within formal assessment frameworks of the Bureau and CSIRO. Assessments of the science delivered by Centre capability is the first point of assessment and most relevant to this Science plan. A limited set of key performance indicators focussing on three dimensions of performance have been selected. These indicators reflect dimensions of:

- Science quality;
- Efficiency and productivity;
- Relevance.

**Quality**

The quality dimension of Centre performance aligns directly with the VISION for the Centre being a world-class Centre.

- Publications in primary peer reviewed literature;
- Citations (lagging);
- Prizes and awards for Centre scientists;
- Appointments to international expert committees and international invitations;
- International Visitors to the Centre more than 50% supported from home institutions.
Efficiency and productivity

The efficiency and productivity dimension can be captured in terms of standard metrics such as publications and citations.

- Number of publications:
  - Peer-reviewed journals;
  - Client reports;
  - Conference papers.

- Citations (either per research scientist or per dollar invested)

- Timeliness of delivery of expected outputs, in support of Bureau services and to research partners, contracting agencies, industry or government.

Relevance

Relevance of the Centre is best assessed against the needs and strategic directions of the Participants and by demand for Centre researchers and capabilities.

- Staff deployment rates (CSIRO);
- Level of investment in the Centre or demand for R&D support by non-R&D programs (Bureau)
- Size and price-points of research contracts;
- Value of contracted research;
- Number of updates to operational systems;
- Demand for Centre input to policy, industry and community processes.

Table 4. Evaluation framework for assessing performance of the Centre against agreed objectives

<table>
<thead>
<tr>
<th>Objective</th>
<th>Measure or indicator</th>
<th>Prior performance</th>
<th>Performance goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>To achieve the critical scientific mass and access to the intellectual capability needed to address and resolve the major scientific problems being encountered in meteorology and related areas;</td>
<td>Qualitative – best evaluated as part of an expert review of the Centre.</td>
<td>Neither organization was able to achieve critical mass in earth system modelling.</td>
<td>To be considered as part of Centre review</td>
</tr>
<tr>
<td>To consolidate and enhance international status of the Participants in the area of earth systems, atmospheric and related research</td>
<td>Qualitative</td>
<td>A review of CSIRO Marine &amp; Atmospheric Research in 2005 rated much research as ‘benchmark’. BMRC research has not been externally reviewed recently.</td>
<td>To be considered as part of Centre review</td>
</tr>
<tr>
<td>Objective</td>
<td>Measure or indicator</td>
<td>Prior performance</td>
<td>Performance goal</td>
</tr>
<tr>
<td>--------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Share (i) an ability to maintain and grow a globally relevant Earth systems modelling capacity,</td>
<td>(i) Global relevance can be assessed through participation in international model inter-comparisons</td>
<td>(i) Coupled model participates in: IPCC, CMIP, OCMIP, GLACE</td>
<td>(i) Participation in CMIP5,</td>
</tr>
<tr>
<td>(ii) an improved ability to deliver science and technological solutions in the Earth systems arena to the Australian community and industry,</td>
<td>(ii) number of updates to operational systems</td>
<td>(ii) BMRC KPI was 10</td>
<td>(ii) NWP suite adopted by Bureau operations includes specialized applications (TC ACCESS-based seasonal prediction system. Delivery of Next-Gen forecast system and gridded OCF</td>
</tr>
<tr>
<td>(iii) Relationships of scale with key clients and</td>
<td>(iii) Average value of Research contracts</td>
<td>(iii) TBD</td>
<td>(iii) Increase in average size</td>
</tr>
<tr>
<td>To resolve long-standing issues of potential duplication between the Participants in atmospheric and related science;</td>
<td>Number of model and model systems used to conduct the research within the Centre.</td>
<td>Models and model systems in use: CSIRO Mk 3, C-CAM, TAPM, RAMS, GASP, LAPS (+ variants), HYSLIT, OFAM, POAMA</td>
<td>All models and numerical modeling applications are based on ACCESS</td>
</tr>
<tr>
<td></td>
<td>Number of shared observing sites and platforms</td>
<td>Cape Grim and the ARM site represented</td>
<td>Development of shared facilities and sites as appropriate and necessary</td>
</tr>
<tr>
<td>To use public funds effectively and efficiently for Earth systems research in Australia;</td>
<td>Price of sub-programs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Each Participant to continue to fulfill its organisational charter in compliance with relevant statutes;</td>
<td>Not to be assessed as part of CAWCR — captured as part of each participant’s performance management framework</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Enable uninterrupted delivery of world-class numerical weather prediction services to the Australian community;</td>
<td>Scientific integrity of systems and services maintained</td>
<td>BMRC benchmark 100% still operating</td>
<td>100% still operating</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Objective</td>
<td>Measure or indicator</td>
<td>Prior performance</td>
<td>Performance goal</td>
</tr>
<tr>
<td>--------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Form integrated science teams within the JRO and share this capability between CSIRO and BoM;</td>
<td>Integrated science team can be measured by number of ‘mixed’ research groups or at the team level. The extent of integration can be measured either as inputs or outputs</td>
<td>All Programs contain researchers from the Bureau and CSIRO</td>
<td>60% of the science is jointly delivered 50% of publications are co-authored by researcher from both partners by end of term Increased contribution to CAWCR from both CSIRO portfolios and Bureau output programs.</td>
</tr>
<tr>
<td>Cooperate on activities within the scope of the JRO;</td>
<td>Captured as the proportion of the activities that can be classed as ‘joint’</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Encourage other collaborative activities between the Participants;</td>
<td>Other examples of other collaborative activities are: Water Information and Research and Development Alliance (WIRADA), HPCCC and Cape Grim Management</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Have a positive impact of science and technology arising from the JRO measured by improved Earth system services for public benefit to the Australian community and increased co-investment by target clients in contracts for research projects;</td>
<td>Percentage co-investment Average ratio of appropriation to co-investment Percentage fully cost-recovered</td>
<td>Current level of co-investment is: Approx 40% CSIRO (C&amp;A Theme only) Approx 31% Bureau (expenditure basis)</td>
<td>Co-investment</td>
</tr>
<tr>
<td>Improve research performance (as measured by citations, skill of models and the like) when normalised by the level of resources committed each year by each Participant; and</td>
<td>A limited suite of skill scores to be reviewed Predictive skill of key models developed by Centre Publication rate per contributed FTE &gt; 1</td>
<td></td>
<td>ACCESS and other next generation models performing in top 20% of international systems</td>
</tr>
<tr>
<td>Maintain mutual trust and confidence between the Participants.</td>
<td>Indicator is effective functioning of the governance arrangements of the Centre</td>
<td>Governance arrangements were agreed at outset of the Centre’s term.</td>
<td>Willingness to enter a second period of joint activity.</td>
</tr>
</tbody>
</table>
ATTACHMENT 1       RESEARCH PROGRAM OBJECTIVES AND DELIVERABLES

PROGRAM 1: ATMOSPHERE-LAND OBSERVATION AND ASSESSMENT

OVERALL OBJECTIVE
To develop the techniques and knowledge to monitor, observe and understand atmospheric and land processes, their interaction, and the role played within Australia’s environment.

Outcomes
- CAWCR playing a leading role in monitoring and assessing the state of the atmospheric environment including greenhouse gases (GHGs), aerosol and reactive species;
- Improved weather, climate and environmental understanding and predictive capability through advanced atmospheric and terrestrial observation systems in the Australian and Southern Hemisphere regions;
- Advances in fundamental knowledge and understanding of the Earth-atmosphere system;
- A greatly improved national capability for observing atmospheric composition and for measuring land-atmosphere fluxes of momentum, mass and energy.

Output Areas
- Long term time series of GHG, aerosol and reactive species for climate change studies and national and international assessments (e.g., Background Air Pollution Monitoring system, the Southern Hemisphere network (GASLAB), ozone network, Darwin Climate Research Station);
- Understanding atmospheric composition and processes spanning local to global scales;
- Input data for weather and related environmental prediction systems;
- Experimental datasets for understanding atmosphere and Earth physical processes, including clouds;
- Data and processes (atmosphere and land) for the development and verification of parameterisations and data assimilation systems;
- Observations & analyses for testing the atmospheric and land surface components of Earth-system climate models.

Specific Goals
- To provide observations for improved understanding of weather and climate processes, including precipitation, clouds, radiation and relevant aspects of the biosphere. Specific applications include the assessment of model output and the impact of cloud systems on the tropical environment;
- To monitor the evolution of the background state of key constituents of the atmosphere in the Australian region (tropics, mid- and polar latitudes) for the purposes of (i) evaluating, constraining and improving models of the earth system; (ii) providing verification of strategies designed to moderate changes to the atmospheric environment;
- Better understanding of the roles of reactive gases and aerosol in the Australian environment particularly the interaction between climate change and composition, also further flow-on effects on the environment and population;
- To evaluate the potential of new and emerging atmospheric and terrestrial observing technologies for sustained (operational) deployment, including assessment of advanced radar techniques for improved rainfall estimation and severe weather detection as well as applications in cloud physics;
- Develop an understanding of the role of the land surface and atmosphere, including the role of biological processes, in governing key biogeochemical cycles of carbon, water, nitrogen and phosphorus. Introduce this knowledge into CABLE;
- Provide the data and methods for increased use of remotely sensed data for NWP data assimilation.

Description
Provide the underpinning observations and analysis of the weather, climate and Earth system, needed for:
- Monitoring the state of the atmosphere and land surface: to detect trends, episodic events and abrupt changes; to evaluate the effect of management strategies; and to assess and manage resources (water, energy, carbon). This requires long-term and continuous observations; high quality data; and effective data analysis, quality control, storage and distribution systems;
• **Model development and testing**: to better understand processes and their representation in models, to parameterise models and quantify model biases, and to provide rigorous and independent verification (benchmarking) of model predictions;

• **Fusing observations with models**: to improve predictions by data assimilation and to diagnose trends and variability in terrestrial energy, water and carbon budgets (e.g. Australia Water Availability Project);

ALOA focuses on land-air exchanges of energy, water, carbon; high quality measurements of the atmospheric composition of radiatively and chemically active gases and particles; terrestrial remote sensing and data assimilation. This includes developing the necessary technologies, maintaining observational infrastructure and integrating observations with models. As such, it has very close links to the ACCESS and Weather and Environment Prediction core capabilities and provides the underpinning for many climate applications.

**Key deliverables**

- Quality assured data suitable for Australia’s contribution to the WMO GAW Baseline Surface Radiation Network, the WMO GAW World Data Centre for Greenhouse Gases (WDCGG – Japan), the WMO GAW World Ozone and Ultraviolet Radiation Data Centre (WOUDC – Canada) and the Carbon Dioxide Information and Analysis Centre (CDIAC – USA);
- Darwin radar data and products to the archive of the US Dept. Of Energy Atmospheric Radiation Measurement (ARM) program;
- Datasets for understanding atmospheric processes, clouds, the radiative balance of the atmosphere;
- Earth observation datasets focusing on land cover and atmospheric composition; land-atmosphere fluxes of carbon, water, heat, momentum, greenhouse gases and volatile organic compounds;
- Precipitation radar based cloud microphysical data for hydrological studies;
- Validation and parameterisations for atmospheric & terrestrial models & data assimilation systems;
- Datasets for testing earth system models (including single column versions) and their components including: biogeochemical, land-surface and air quality modules;
- Data assimilation: new methods for assimilating earth observation data;
- Analyses of atmospheric composition and processes;
- World-class peer-reviewed publications;
- Significant contributions to national and international assessments of climate change science; and
- Advice and guidance for policy makers and environmental managers.

**Performance Indicators**

- Timely availability of relevant, up to date datasets for model verification and for process studies in the atmosphere and terrestrial ecosystems;
- Maintenance of, and compliance with, quality assurance protocols for data from the DCRS, BSRN and GAW networks;
- Advances in validation and parameterisation of atmospheric and land surface processes;
- Number of published, world-class, peer-reviewed scientific papers;
- The number of new satellite datasets integrated into the data assimilation system;
- Development and successful execution of new projects that bring together the capabilities in the Bureau and CSIRO including Cape Grim and other Southern Hemisphere observations and their interpretation through models; as well as interactions between the land-surface ,cloud systems and climate.

**Resources**

- 66 staff with a mixture of scientists, engineering, IT and technical support;
- Extensive laboratory facilities for atmospheric composition;
- Extensively instrumented field sites at Darwin, Cape Grim, Tumbarrumba, Macquarie Island, Otways, Brisbane and other locations.

![The Cape Grim Baseline Air Pollution Station supplies vital information about changes to the atmospheric composition of the Southern Hemisphere.](image)
PROGRAM 2: OCEAN OBSERVATION, ASSESSMENT AND PREDICTION

OVERALL OBJECTIVE
To observe, monitor and understand the key processes that drive variability and change in Australia’s regional ocean waters and apply that understanding to model and predict the behaviours of the oceans of the Australian region and their role in regional and global climate.

Outcomes
- A leading role in monitoring and assessing the state of the ocean environment including contributions to a national capacity for observing the oceans;
- Advanced systems for providing oceanic and marine meteorological observations for ocean, climate and weather prediction;
- Fundamental knowledge and understanding of earth system science and climate processes, specifically in the area of coupling and interaction of the ocean with the atmosphere and hydrosphere;
- Improved maritime safety through the application of research delivered via the Bureau of Meteorology systems including reliable warnings for ocean-related natural hazards;
- An enhanced basis for understanding and predicting the state of the ocean and for improving the management of, and services for the marine environment; and
- Transformational changes in the application of ocean prediction for services supporting safer and more efficient operations in the ocean, including for defence and security purposes, and enhanced social and economic benefits.

Output Areas
- Contributions to the “Bluewater” component of the Australian Integrated Marine Observing System;
- Complementary deep-sea and satellite observations for climate change studies in the Australian and Antarctic regions, and the deployment of satellite observations for the initialisation of marine forecasting and analysis;
- Datasets and analyses for the oceans surrounding Australia;
- Knowledge and understanding of key processes that are integral to air-sea interaction and climate modelling such as the subduction rates of key water masses, the strength of ocean mixing processes and the ocean’s role in ENSO;
- Public good ocean forecasts;
- Contributions to improved sea state and marine meteorological forecast systems;
- Products and services for defence applications;
- Science supporting the Australian Tsunami Warning System;
- Ocean forecasting, reanalysis and knowledge for coastal prediction systems and related ecosystem research.

Specific Goals
- Establish a national prototype ocean observation system as part of a national Integrated Marine Observing System suitable for providing observations for the initialisation and verification of earth system models and for detecting and attributing changes in the climate of the oceans;
- To develop new insights into the behaviour of the ocean, its variability and predictability, and its interaction with other components of the earth system with a focus on the Australian region;
- To improve our understanding of the ocean processes that play key roles in ENSO so that we will be able to improve the behaviour of ENSO in coupled climate models;
- To develop ocean prediction systems, including implementation of the BLUElink system for mesoscale ocean prediction and reanalysis;
- To develop and implement a coupled ocean-atmosphere regional prediction system, including support of the Australian Tsunami Warning System and new and improved methods for assimilation of ocean observations into ocean and Earth system models;
- To validate and develop improved marine meteorological analysis and forecast systems, particularly with respect to surface wind stress.

Description
This research group provides fundamental knowledge of the variability of the ocean on all time scales and from the deep ocean to the surface marine environment. It uses a range of observational methods and analyses to understand important processes and mechanisms of variability and change in the ocean to develop understanding of the interactions of the ocean with the atmosphere land and hydrosphere in the coupled Earth system. The scope extends from tropical waters to the sea-ice boundary of the Southern
The Ocean Prediction Stream will produce a new generation of ocean forecasting products. The Research Group will contribute directly to the development and testing of model parameterisations and data assimilation. This knowledge underpins the development of models and practical prediction systems based on improved model and data assimilation systems. Program researchers will exploit the huge potential offered by rapid advances in eddy-resolving ocean models, new data streams from satellites (e.g., sensing sea-surface temperature, sea surface height, ocean colour) and other sensors (e.g., Argo floats, gliders, surface buoys, HF-radars), new data assimilation techniques, and high performance computing and information technologies to deliver ocean state and Metocean products and services. These scientific advances will enhance maritime safety, deliver a competitive edge to the Royal Australian Navy as well as providing improved warning for natural hazards associated with the ocean.

Key Deliverables
- An Indian Ocean Thermal Archive;
- Subsurface observations and quality controlled datasets from profiling floats and other instruments;
- A “Bluewater” component to an Integrated Marine Observing System;
- Complementary ocean observations focused on the Southern Ocean using deep section and underway technologies; and
- Scientific knowledge applied to Australia’s Ocean Policy and State-of-the-Environment reporting and assessments.
- Ocean reanalysis products;
- A world-class ocean prediction system for the Royal Australian Navy and the Australian ocean community;
- Scientific knowledge applied to Australia’s Ocean Policy and State-of-the-Environment reporting and assessments;
- Systems and products for monitoring the state of, and improving management of the ocean environment;
- Data (e.g., boundary conditions) and information for coastal research and related monitoring and prediction systems;
- Australian Tsunami Warning System research components.

Performance Indicators
- Reduced error of ocean forecasts and re-analyses;
- Knowledge and understanding of ocean variability and predictability;
- Refereed publications, client reports and presentations;
- Transfer of technology into operations, including improved services to, and uptake by, the Royal Australian Navy and other key stakeholders;
- Intellectual property and research service potential in the general area of oceanography;
- Systems and products for monitoring the state of, and improving management of the ocean environment;
- Quality controlled datasets, assessable nationally and internationally.

Resources
- 52 Staff;
- Access to the National Facility Research vessel;
- Continual access to satellite and other remote sensing data streams;
- Laboratory and equipment support facilities;
- Access to supercomputing resources at the HPCCC and NCI facility.
PROGRAM 3  EARTH SYSTEM MODELLING

OVERALL OBJECTIVE
To lead development of a world-competitive coupled climate and earth system simulation and modelling system for the Australian community and the establishment of national comprehensive Earth system science capability.

Outcomes
- Australia has the capacity and capability in climate and Earth system modelling for:
  - weather forecasting;
  - environmental prediction (including flood forecasting, natural hazard management, air quality and forecasting related to energy supplies);
  - seasonal to inter-seasonal prediction of climate and analysis of natural climate variability;
  - ocean prediction;
  - projections and analysis of climate change (including detection and attribution of climate changes, projecting climate and assessment of impacts).
- National knowledge and resources are applied optimally through implementation of a ‘team Australia’ approach to the development of next generation earth system simulator as a result of enhanced collaboration with the wider research community and in particular the Universities;
- Improved leverage from the international model development community;
- Australia is better equipped to make informed decisions based on the interactions between human social, demographic, economic and policy activities and non-human Earth systems, including climate, pathogens and global natural events.

Output Areas
- A new national capability in numerical weather prediction that includes advanced data assimilation techniques and better use of satellite and in-situ data;
- A coupled atmosphere-ocean/sea-ice-land surface/carbon cycle model suitable for participation in the major international programmes such as the Intergovernmental Panel on Climate Change Fifth Assessment Report;
- An enhanced capability for seasonal prediction and related decision making;
- An enhanced capability in ocean modelling systems that includes advanced data assimilation techniques and utilises satellite and in situ data;
- Earth system modelling infrastructure (e.g., software engineering standards, model diagnostics);
- Innovative capacity for integrated assessment of human interactions with the non-human Earth system.

Specific Goals
- Develop a fully coupled Earth Systems Model comprising the atmosphere, ocean/sea-ice, land-surface/carbon cycle, ocean carbon cycle and atmospheric Chemistry that can function seamlessly across time-scales from ‘weather’ (hours), and climate (seasons-years) to climate change (decades-century) and through spatial scales from global to national through to local (potentially <1 km2);
- Provide the Australian Bureau of Meteorology with world-leading Numerical Weather Prediction capability to underpin the Australia’s basic weather services;
- Deliver credible simulations of the future state of the earth system for the IPCC 5th Assessment;
- Provide a high resolution, limited area, nested modelling capability for ‘dynamical downscaling’ of climate change and for applications related to the management of natural resources;
- Incorporate innovations from Australian universities and partner with them so that ACCESS is the system of choice within the Australian university science community;
- Develop modelling and assessment systems for coupled climate and Earth system – economic – social analysis and projection.

Description
This group occupies the hub of the Centre and interacts strongly with all other groups. It provides the core capability to provide Australia with the next generation capability for weather prediction and for diagnosing, analysing and forecasting Australia’s climate-sensitive natural resource systems (rainfall, soil water, vegetation) to improve management throughout the coming decades. It brings together CSIRO and the
Bureau resources to establish for the first time a critical mass in earth system modelling. The group collaborates strongly with Australia’s universities particularly in the evaluation of the modelling system. The ACCESS group also manages strategic collaborations with other international groups that are developing earth system models notably the United Kingdom MetOffice, the National Oceanographic and Aeronautical Administration’s Geophysical Fluid Dynamics Laboratory, the Lawrence Livermore National Laboratory, and the European Centre for Medium Range Weather Forecasts.

**Key deliverables**
- A transformational change in numerical weather prediction for Australia;
- A modeling system that can generate output suitable for inclusion in the 5th IPCC Assessment;
- Infrastructure (coupling technology, software engineering and code maintenance, standards, protocols for adoption of innovations, standard and consistent diagnostics, user interfaces) for the science of earth system simulation that is accessible across Australia’s research community;
- A capability to dynamically ‘down-scale’ simulations from global to regional scales;
- An active program of exchange between Australian scientists working on ACCESS and the UK MetOffice that ensures Australian innovations are adopted within the unified model and that the most recent developments in modeling science are available for the public benefit;
- Tools for integrating earth system science with impacts assessment for integrated assessments.

**Performance Indicators**
- Adoption of ACCESS as the basis for the Bureau of Meteorology NWP system;
- Improvement of skill-scores relative to the currently operational numerical weather prediction systems;
- Participation of ACCESS in the Intergovernmental Panel on Climate Change 5th Assessment Report through submission of a full set of ACCESS experiments for IPCC assessment;
- The ACCESS model performs within parameters acceptable to the international community;
- The number of university users of the ACCESS system and the level of University contributions to the continuing development of ACCESS;
- ACCESS developments adopted and returned through the UK MetOffice and GFDL; and
- The most up-to-date unified model and other modules (eg ocean code, coupling technologies) are available to the ACCESS stream;
- Australian climate adaptation and mitigation strategies are well informed about likely feedbacks to the Earth system;
- Australia is well prepared to respond to contagions in human and animal populations.

**Resources**
- 56 research staff;
- Access to supercomputing resources at the High Performance Computer & Communications Centre (HPCCC);
- Access to supercomputing resources at the National Computational Infrastructure Facility;
- Access to data input streams for model parameterisation, validation and assessment.

*Proposed modules for the ACCESS Earth Systems Simulator*
PROGRAM 4: WEATHER AND ENVIRONMENTAL PREDICTION

OVERALL OBJECTIVE

To improve understanding of atmospheric processes and develop and apply numerical weather prediction systems for advanced weather forecasting and related environmental services including prediction and monitoring of severe weather and air pollution hazards and generation of climate projections.

Outcomes

Research within this stream significantly reduces the cost to the Australian community of weather hazards, atmospheric pollution and underpins new services.

- Application of the research will improve emergency response particularly for floods, bushfires, tropical cyclones and other extreme weather events;
- New and enhanced technologies for weather and environmental services;
- An improved community understanding of the short-term and long-term risks to the Australian community and its industries and economy from weather hazards, atmospheric pollution and extreme events, now and as a result of climate change;
- Enhanced public and private sector take-up of weather research and forecast services, including use of uncertainties and improved emergency response particularly for floods and bushfires;
- A better informed community on the risks from atmospheric pollution and the catastrophic release of dangerous or toxic substances to the atmosphere; and
- Transformational changes in the use and adoption of weather research and associated services in decision making systems.

Output Areas

- Public good weather forecasting;
- New and more informative precipitation forecasts and products, on all time scales;
- Research underpinning aviation services;
- Environmental forecasting including air quality and atmospheric exposure forecasts, bushfire weather and associated air quality impact assessments, and forecasts for emergency response;
- Hydrological forecasting for flood risk and extreme weather events (e.g., tropical cyclones) forecasting;
- Climate projections at regional scale to facilitate long-term planning; and
- Knowledge and understanding of atmospheric processes and weather.

Specific Goals

- To develop, assess and test global, regional and mesoscale weather prediction systems, as well as regional climate modelling systems, in concert with the ACCESS group;
- To increase the range, quality and availability of environmental forecasts available to the Australian community and industry, especially those related to:
  - air quality (particularly, wind-blown dust, bushfire smoke and urban pollutants)
  - atmospheric aspects of bio-security (e.g., air-borne viruses)
  - emerging renewable energy markets.
- Progress the science of very short term forecasting and support the development and application of nowcasting techniques and related procedures in the Bureau;
- To provide support for the aviation industry through research into improved weather and warning services;
- To advance the science of the weather forecast process through the development of new forecast systems and procedures, and apply these techniques for use within the Bureau weather services;
- To improve understanding of high impact weather events including tropical cyclone and monsoon dynamics and predictability; and
- To improve knowledge and skill for forecasting of rainfall and precipitation characteristics, and hydrological events including floods.
Description
The Weather and Environmental Prediction Program draws together Bureau of Meteorology and CSIRO capability in the application of numerical weather, tracer and chemical transport prediction, air pollution and data analysis and interpretation to improve public weather forecasting and to exploit new opportunities in environmental prediction. This program’s capabilities focus particularly on processes occurring from minutes to weeks with an emphasis on finer spatial scales. With a major focus on improving the public good forecasting within the Bureau, the science conducted within this group is also applied to a wide variety of other applications including: forecasting within energy markets and for renewable energy generation, routine application in aviation, emergency response to atmospheric emergencies (e.g., toxic gas releases) and for public environmental health purposes. As the centre of expertise in the meteorology and dynamics of high impact weather events, the group also plays an important role in detection, attribution, and prediction of extreme events under climate change. The science outputs deliver to improving National Meteorology and Oceanographic Centre outcomes.

Key deliverables
- Specialised forecasting systems within ACCESS including tropical cyclones, ozone/UV, and Antarctic weather;
- Forecast system for public good weather forecasting: Scientific development of a next generation forecast and warning system;
- Operational consensus forecast system;
- Advances in knowledge and understanding of high impact weather systems, including heat waves, thunderstorm complexes, east coast lows, severe wind events and tropical cyclones;
- Reports on the meteorological causes of major weather events affecting Australia and its territories;
- Radar Applications: Development of radar-based interpretation and display systems for detection and warning of hazards and for quantitative precipitation estimation and forecasting;
- Aviation forecasting and defence support Integration of aviation and defence weather applications with bureau forecast systems;
- Environmental forecasting: Improved air quality forecasting systems and estimates of health risk from natural and anthropogenic air pollutants; and
- Regional-scale climate projections of future weather and air quality characteristics and trends.

Performance Indicators
- Advances in understanding of causes and evolution of extreme weather events;
- Transfer of scientific and technical knowledge via presentations and training;
- New products derived from weather and air quality research;
- Successful development and improvement of Bureau of Meteorology operational systems including systems for data analysis, weather forecasting, warning and decision making, and verification;
- Successful partnerships and consultancies with government, industry and external clients;
- High quality publications on weather, climate, air quality, and forecast process research;
- Explicit recognition of research impact in risk reduction; and
- Participation in national and international fora on research relevant to the Program and international recognition of Program researchers.

Resources
- 44 research staff;
- Access to ICT resources including supercomputing resources at the HPCCC;
- Access to the Bureau’s operational field observing technologies including radar and regular data streams.
PROGRAM 5: CLIMATE VARIABILITY & CHANGE

OVERALL OBJECTIVE

To provide predictions of future Australian climate from seasonal to century scales and deliver climate information to inform policy for managing Australia’s environmental resources, climate dependent industries, and climate change mitigation and adaption strategies.

Outcomes

- Improved natural resource management across all sectors of the Australian community through the better knowledge of climate variability and predictability at seasonal scales;
- Decreased climate risk in agricultural production and better informed water resource management;
- Knowledge, data and tools used in regional and sectoral risk assessments;
- The Australian public and Australian industries and organisations are better informed of the likelihood and nature of past and future climate change in the Australian region;
- Knowledge of how much climate change Australia needs to adapt to and by when;
- Australia is better equipped for practical and effective adaptation and mitigation responses to climate change and variability.

Output Areas

- Seasonal-to-inter-annual climate prediction systems;
- Climate prediction products and advice in support of Bureau, relevant CSIRO flagships and a range of external stakeholders;
- National and regional assessments of current changes in climate and projections of expected future climate change, including changes to extreme weather events;
- Studies to attribute the causal factors leading to the observed climate changes;
- Assessment and projections of regional sea level rise, trends in wave climates, and extreme sea level events and their consequences for Australian and regional communities and coastal environments;
- Development of integrated approaches to climate change adaptation.

Specific Goals

- To Generate projections of climate change for use in national and regional impact and adaptation assessments;
- To develop and apply appropriate techniques to historical and contemporary climate and environmental data to generate datasets suitable for monitoring and understanding climate change and its impacts;
- To develop an improved understanding of key processes driving long term climate variability and change and to identify the nature and causes of significant climate anomalies and trends having consequences for hydrological systems and water resources;
- To Improve projections of sea-level rise, waves and extreme sea level events along the Australian and Indo-Pacific regional coastlines;
- To progress the science of seasonal-to-inter-annual climate prediction, including the development of the next generation of coupled dynamic seasonal prediction models for intra-seasonal and seasonal applications (POAMA/ACCESS);
- To advance understanding of climate variability and predictability by using climate data and coupled models to complete theoretical and practical studies;
- To contribute to risk management and decision making tools sensitive to seasonal-to-inter-annual climate variability, in the general areas of natural resource management and primary industries and useful to diverse external stakeholders;

Description

Australia experiences high inter-annual climate variability that affects all facets of natural resource management. The economic and social impacts of this variable climate, whether expressed in terms of pressure on water resources, reduced crop yields, damage to grazing industries, dislocation of local communities or severe fire seasons, is significant (a severe drought typically reduces national GDP by 1%). There is a very clearly expressed national need for much improved insight into inter-seasonal climate variations that integrates with management systems to improve tactical management in agricultural production and water management. Work in this program will harness and redirect existing resources within the Bureau...
and CSIRO Marine and Atmospheric Research to provide a more effective response to the challenge of interseasonal climate variability occurring within the broader context of human-forced climate changes.

This program also brings together CSIRO Marine and Atmospheric Research and the Bureau of Meteorology Research Centre’s unique capabilities in the assessment, detection attribution and projection of climate change. Thus, the program provides the earth system science basis for integrated assessments of (i) the prognosis for climate change in Australia and the Australian region; (ii) the impacts of climate change for Australia and the Australasian region; and (ii) the likely effectiveness of response measures to mitigate the magnitude of future change and adapt to changes that are recognised as inevitable.

Key deliverables
- Next generation systems for dynamic modelling and prediction of climatic variability and trends for Australia at near to seasonal timescales (POAMA & ACCESS) to underpin the Bureau of Meteorology’s next-generation seasonal forecasting services;
- An assessment of the potential predictability of Australia’s climate including rainfall;
- Publications on the mechanisms of climate variability relevant to Australia;
- Projections of climate change over Australia and our near neighbours that include probabilities and outputs tailored to the needs of users;
- Assessments of the nature of significant climate processes, anomalies and trends and their consequences for hydrological systems and water resources and the coasts of Australia and its regional neighbours;
- Observational and modelling studies of processes contributing to sea-level rise and extreme sea level events, including storm surges, and waves affecting Australian coasts and coastal areas in the Australasian region;
- Methods and tools for integrated risk assessment, including assessment of adaptive capacity and vulnerability.

Performance Indicators
- Successful development of operational-quality dynamic seasonal prediction systems and adoption of model products in seasonal-to-interannual climate services;
- Delivery of regional seasonal climate knowledge and predictions for use in tactical resource management;
- Publications appearing in international journals;
- Increased co-investment in seasonal to interannual climate work within CAWCR and from external agencies;
- Uptake of research outputs in public policies (e.g., State and Commonwealth Greenhouse Strategies);
- Refereed publications, client reports, presentations, media reports, and national and international recognition of program researchers;
- Delivery of highly valued products and services to key clients: e.g., three levels of government (particularly the DCC through the Australian Climate Change Science Programme), NGOs (such as the Climate Institute and WWF), industry (such as agriculture, water, tourism, health, energy, infrastructure), the media, the Australian general public and, where asked, Australasian regional communities (through Australian aid activities);
- Significant contribution to the Intergovernmental Panel on Climate Change.

Resources
- 69 research staff;
- Access to supercomputing resources at the HPCCC;
- Access to the outputs from national and international global climate models.

Improved seasonal climate applications will assist sustainable management of natural resources
TABLE OF ACRONYMS

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACCESS</td>
<td>Australian Community Climate and Earth System Simulator</td>
</tr>
<tr>
<td>ACCSP</td>
<td>Australian Climate Change Science Program</td>
</tr>
<tr>
<td>ACE CRC</td>
<td>Antarctic Climate and Ecosystems Cooperative Research Centre</td>
</tr>
<tr>
<td>ATWS</td>
<td>Australian Tsunami Warning System</td>
</tr>
<tr>
<td>BMRC</td>
<td>Bureau of Meteorology Research Centre</td>
</tr>
<tr>
<td>BoM</td>
<td>Bureau of Meteorology</td>
</tr>
<tr>
<td>BRAN</td>
<td>BLUElink reanalysis</td>
</tr>
<tr>
<td>BSRN</td>
<td>Baseline Surface Radiation Network</td>
</tr>
<tr>
<td>CDIAC-USA</td>
<td>Carbon Dioxide Date Interpretation and Analysis Center – United States of America</td>
</tr>
<tr>
<td>CMAR</td>
<td>Commonwealth Scientific and Industrial Research Organisation, Marine and Atmospheric Research</td>
</tr>
<tr>
<td>CRC</td>
<td>Cooperative Research Centre</td>
</tr>
<tr>
<td>CSIRO</td>
<td>Commonwealth Scientific and Industrial Research Organisation</td>
</tr>
<tr>
<td>ESS</td>
<td>Earth Systems Science</td>
</tr>
<tr>
<td>GASLAB</td>
<td>Global Atmospheric Sampling Laboratory</td>
</tr>
<tr>
<td>GAW</td>
<td>Global Atmosphere Watch</td>
</tr>
<tr>
<td>GDP</td>
<td>Gross Domestic Product</td>
</tr>
<tr>
<td>GFDL</td>
<td>Geophysical Fluid Dynamics Laboratory</td>
</tr>
<tr>
<td>HPCCC</td>
<td>High Performance Computing and Communications Centre</td>
</tr>
<tr>
<td>IAWG</td>
<td>Impacts and Adaptations Working Group</td>
</tr>
<tr>
<td>IOCI</td>
<td>Indian Ocean Climate Initiative</td>
</tr>
<tr>
<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change</td>
</tr>
<tr>
<td>JAFOOS</td>
<td>Joint Australian Facility for Ocean Observing Systems</td>
</tr>
<tr>
<td>JRO</td>
<td>Joint Research Operation</td>
</tr>
<tr>
<td>MJO</td>
<td>Madden Julian Oscillation</td>
</tr>
<tr>
<td>MOM 4</td>
<td>Modular Ocean Model</td>
</tr>
<tr>
<td>NCC</td>
<td>National Climate Centre</td>
</tr>
<tr>
<td>NMOC</td>
<td>National Meteorological and Oceanographic Operations Centre</td>
</tr>
<tr>
<td>NOB</td>
<td>National Observations Branch</td>
</tr>
<tr>
<td>NTC</td>
<td>National Tidal Centre</td>
</tr>
<tr>
<td>NWP</td>
<td>Numerical Weather Prediction</td>
</tr>
<tr>
<td>OEB</td>
<td>Observations and Engineering Branch</td>
</tr>
<tr>
<td>POAMA</td>
<td>Predictive Ocean-Atmosphere Model for Australia</td>
</tr>
<tr>
<td>SST</td>
<td>Sea-surface temperature</td>
</tr>
<tr>
<td>UKMO</td>
<td>United Kingdom Meteorological Office</td>
</tr>
<tr>
<td>WIHC</td>
<td>Water for a Healthy Country Flagship</td>
</tr>
<tr>
<td>WIO</td>
<td>Wealth from Oceans Flagship</td>
</tr>
<tr>
<td>WMO</td>
<td>World Meteorological Organisation</td>
</tr>
<tr>
<td>WMO GAW</td>
<td>World Meteorological Organisation Global Atmosphere Watch Programme</td>
</tr>
<tr>
<td>WDCGG - Japan</td>
<td>World Data Centre for Greenhouse Gases - Japan</td>
</tr>
<tr>
<td>WOUDC - Canada</td>
<td>World Ozone and Ultraviolet Radiation Data Centre - Canada</td>
</tr>
<tr>
<td>WOSPB</td>
<td>Weather and Ocean Services Policy Branch</td>
</tr>
<tr>
<td>WRON</td>
<td>Water Resources Observation Network</td>
</tr>
</tbody>
</table>