The Australian Community Climate and Earth System Simulator, ACCESS: Scientific justification and options for system development

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The Australian Community Climate and Earth System Simulator (ACCESS) is a coupled climate and earth system simulator being developed as a joint initiative of the Bureau of Meteorology and CSIRO in cooperation with the university community in Australia. The main aim of ACCESS is to develop a national approach to climate and weather prediction model development. Planning for ACCESS development commenced in 2005 and significant progress has been made subsequently. This paper provides an account of the scientific justification of the scope and options considered for ACCESS development.

Introduction

Early in 2005, the Bureau of Meteorology and CSIRO made a decision to jointly develop a fully coupled earth system model, the Australian Community Climate and Earth System Simulator (ACCESS).

The key objectives of ACCESS were to create models and modelling outcomes that:

• assist the Bureau of Meteorology in meeting its statutory requirements in providing the best possible meteorological services;
• assist CSIRO by providing the best possible science for use in analysing climate impacts and adaptation, and related fields;
• meet policy needs in natural resource management and related fields for scientific information and analysis;
• develop synergy with research in numerical weather prediction and seasonal forecasting and enable climate change scenarios;
• provide substantive linkages with relevant university research; and
• are world-class, and so will enable Australia to meet the long lead times necessary to contribute to national and international programs such as the Fifth Assessment by the Intergovernmental Panel on Climate Change.

Thus ACCESS was aimed at developing a national approach to climate and weather prediction model development that was grounded on well engineered and realistically achievable software and supported by high quality IT infrastructure. The system had to be flexibly engineered so as to be capable of allowing for fresh and new applications in related fields.


The Blueprint and the Project Plan provided an analysis of ACCESS stakeholder requirements; developed the scope for ACCESS, based on these requirements and an analysis of earth system models (ESMs) in use at a number of key international centres; and made recommendations for the preferred options for the components, together with an estimate of the level of investment required for ACCESS to achieve its required objectives. Development of ACCESS has followed the recommendations made in the Project Plan with significant collaboration with international partners, particularly the United Kingdom Met Office and the USA/NOAA Geophysical Fluid Dynamics Laboratory.

This paper, which is based on the Blueprint and the Project Plan, sets out to recount the scientific and stakeholder rationale for seeking a more comprehensive, integrated earth system modelling platform, and describe the logic and reasoning behind the ACCESS system. The accepted options
for ACCESS are described, followed by a brief summary of the implementation and concluding remarks.

**Justification for the project expressed in terms of outcomes**

Climate variability and change have a major influence on the social and natural environments, and major climate research programs have been aimed at determining the extent to which climate can be predicted, and to determine the extent of the human influence on climate. A further aim of the programs is to achieve a deeper and more quantitative understanding of the role of human perturbations to biogeochemical cycles in altering the coupled climate system.

The past decade has seen major improvements in our ability to provide accurate weather forecasts over the one to ten day timescales. These improvements are a result of a number of factors such as major increases in the observation network and more particularly in satellite data from a wide variety of sensors that provide high-resolution (in time and space) information on key atmospheric variables, development of analysis and assimilation methods that allow effective use of these data, improvements in all components of numerical models (including resolution increases) and development of comprehensive methods to verify and diagnose model output. Despite the notable increase in forecast skill, there are still deficiencies in our ability to accurately predict high-impact weather systems that can have significant impact on society, the economy and the environment; examples of these systems include heavy precipitation, flooding, tropical cyclone landfall, destructive surface winds etc. Improving the skill of high-impact weather forecasts is a major scientific and societal challenge.

As noted in the ‘The World Climate Research Programme Strategic Framework 2005-2015’ (WCRP-123 WMO, TD-No.1291), developments in atmospheric science and technology provide the opportunity to address the predictability of the total climate system for the benefit of society and to address the seamless prediction of the climate system from weekly weather to seasonal, decadal and centennial climate variations and anthropogenic climate change. The key requirements for developing an adequate research strategy for addressing the above issues include:

- adequate observation network and ready access to data;
- process studies to understand the key processes driving the climate system;
- earth system models that couple important processes driving the climate system, including an adequate infrastructure that allows easy access to researchers;
- data assimilation systems that allow data from a wide variety of observation platforms to be assimilated;
- applications such as weather prediction and climate/ climate change projections, and
- effective means of communicating results to users and decision-makers.

ESMs are essential tools required to address the so-called seamless climate prediction problem. A key aspect in the development of ESMs is their increasing complexity with the inclusion of the atmosphere, land surface, ocean and sea-ice, aerosols, carbon cycle and atmospheric chemistry. An important aspect of numerical weather prediction (NWP) and seasonal prediction systems is the inclusion of complex data analysis and assimilation methods that provide the capability of assimilating data from a wide range of observation systems, particularly from satellites. A recent development in NWP is the move towards global environment monitoring systems that require prediction and assimilation of greenhouse gases and other chemical species (such a system is already being run at the European Centre for Medium Range Weather Forecasts (ECMWF) under the European project Monitoring Atmospheric Composition and Climate (MACC) to provide daily analyses and forecasts). Ocean data assimilation is now used routinely and operationally in conjunction with coupled atmosphere-ocean models for seasonal prediction. Similarly initialisation (or spin up) of the land surface variables through data assimilation has been receiving increased attention. Although coupled data assimilation is currently at a very early stage, it is an area that will see major activity in the future.

Some of the major centres that have developed ESMs include the Met Office Hadley Centre for Climate Prediction and Research (UK), National Centre for Atmospheric Research (USA), Max Planck Institute (Germany), the Geophysical Fluid Dynamics Laboratory (USA), Institut Pierre Simon Laplace (France) and the Frontier Research System for Global Change (Japan). Short- to medium-range and seasonal predictions are provided operationally at a number of centres around the world, including the Bureau of Meteorology.

The “Strategic Plan for the U.S. Climate Change Science Program” (2003) notes the following key questions relating to climate variability and change.

- To what extent can uncertainties in model projections due to climate system feedbacks be reduced?
- How can predictions of climate variability and projections of climate change be improved, and what are the limits of their predictability?
- What is the likelihood of abrupt changes in the climate system such as the collapse of the ocean thermohaline circulation, inception of a decades-long mega-drought, or rapid melting of major ice sheets?
- How are extreme events, such as droughts, wildfires, heatwaves, and hurricanes, related to climate variability and change?
- How can information on climate variability and change be most efficiently developed, integrated with non-climatic knowledge, and communicated in order to best serve societal needs?

Similar questions motivate the strategy for short- to medium-range and seasonal predictions, namely:

- How can uncertainties in model forecasts be predicted and reduced?
- What are the limits of deterministic prediction?
• How can the prediction of extreme weather events such as heavy rainfall, destructive winds, tropical cyclone tracks and intensities, heatwaves, onset of monsoons be improved and provided in a timely manner?
• How can information on extreme events, air quality etc. be most efficiently delivered to users in order to best serve their needs?

These questions are highly relevant for Australia. Thus for example there are requirements for provision of weather and seasonal forecasts; effective linking of climate change research to decision-making by government agencies on issues such as fossil fuel production; distillation of the results of climate change research to critical information targeted at decision-makers and resource managers within and outside government; and the study of the impacts of extreme events on Australian society and industry.

There have been two options available to Australian researchers in order to address the above questions. Under the first option an argument could be made that earth system science is international and that Australian researchers could rely on output from international models or use these models to conduct their research; indeed there was and still is a group of researchers that would be satisfied to work with IPCC Assessment model runs from non-Australian models, for example. However, although this approach might appear to be attractive, there is a clear danger that it would severely limit our capabilities to adequately study local issues. For example the credible linking of impacts with climate change requires the formal identification of such changes and determination of their cause and this can only be done through detailed experimentation which would be severely restricted if we had to rely solely on output from overseas models. Similarly in cases of severe weather or special events, such as the Sydney Olympics or for emergency response requirements such as the fires over Victoria in February 2009, the 2011 Queensland and Victorian floods, and tropical cyclones making landfall (e.g. tropical cyclone Yasi) there might be an operational requirement for additional (high-resolution) model runs; this is obviously not possible using overseas model output. Another important reason for having a strong Australian modelling capability is to provide a southern hemisphere focus as most other efforts tend to be focussed on the northern hemisphere.

The second option recognises the fact that Australia has a proud history in all aspects of atmospheric/oceanic research and modelling, and has a prominent profile and impact in international circles. Bureau and CSIRO models have been very well represented internationally in NWP and climate/climate change communities and in major model intercomparison projects such as the Atmospheric Model Intercomparison Project (AMIP), Coupled Model Intercomparison Project (CMIP, Taylor et al. 2012), Climate of the Twentieth Century (C20C) project, and in the assessment reports of the IPCC. It is important that Australia continues to maintain a strong scientific presence in climate/climate change science and weather prediction in order to provide the local and southern hemisphere focus. In addition, this presence is important to ensure that we are able to attract younger scientists into the field and to provide them with fulfilling research careers to ensure that the Australian community can benefit from future developments in the field.

The complexity of ESMs and meteorological and oceanographic data assimilation science has expanded dramatically over the last twenty years. The scope of the advanced science and technology that underpins leading practice in these fields is such that it requires significant resources in research and development and in the infrastructure enabling the strategic and tactical application of the science. This was and still is the clear message from the centres delivering the most successful outcomes. By these measures the aggregate personnel resources available to the Bureau and CSIRO, for example, to pursue these fields were sub-critical relative to these centres. That Australia was an early significant contributor in this science reflects the then scope for individual scientists to make an individual contribution within a developing field. Major coordination and focused team research is now necessary to address the breadth and present levels of complexity of the scientific issues.

In the past decade there have been clear signs that Australia was in serious risk of falling behind in climate/ climate change modelling and numerical weather prediction. Indications of this are evident in comparing the Bureau’s previously operational global model (the Global Assimilation and Prediction (GASP) system, Bourke et al. 1995; Seaman et al. 1995) performance with overseas models (see Fig. 1) which indicates a significant gap between the local operational model and models from major international centres, and from our decreased contributions to international climate/ climate change intercomparisons. As noted above ESMs are highly complex systems that require high level of resources, in terms of experienced and specialist scientists and software engineers, to develop and maintain a state-of-the-art system.

Fig. 1. Comparison of skill scores in the Australian region for 24 h forecasts from GASP (green and yellow curves) with overseas operational models – ECMWF (red), Met Office (magenta), Japan Meteorological Agency (cyan), National Centres for Environmental Prediction (blue).
One effective way to resolve the issue and to halt the slide in our modelling capabilities was to pool resources to develop a unified Australian system, as was proposed under ACCESS.

A further justification for development of ACCESS was to provide a common modelling infrastructure that could be readily used by researchers from other Australian institutions, particularly the Australian universities. The user community is potentially much larger than the developer community and accordingly a core community model framework as envisaged for ACCESS had the scope to catalyse significant research and process studies with these complex systems within this wider community. Additionally by providing students with an opportunity to develop and use its components, ACCESS would ensure that Australia continued to have a world-class cadre of graduates with modelling experience.

**Consideration of stakeholders addressed by the project, and the related liaison requirements**

The main stakeholders for the initiation of ACCESS were the Bureau of Meteorology, CSIRO, Australian universities and the Department of Climate Change and Energy Efficiency. An analysis of requirements of the stakeholders emerged as follows.

- A comprehensive modelling system including data assimilation and the capability to generate ensembles that could be used for a wide range of time and space scales associated with numerical weather prediction, seasonal prediction, climate and climate change.
- A modelling system that was world-class and portable so that it could be run on a variety of computing platforms; additionally there was a requirement for the system to be flexible, for example in allowing choice of boundary conditions from the ocean or laterally from the atmosphere.
- The system had to be available for participation in CMIP5 in time for inclusion of results in the IPCC Fifth Assessment Report.
- A modelling system that would allow for detailed process and attribution studies; a particular emphasis of these studies would be on the Australian region which required that ACCESS should provide a capacity to enable regional downscaling.
- A modelling system that was well documented, robust and included comprehensive verification procedures to ensure high-level performance.
- A highly developed computing infrastructure developed and maintained by computing and software engineering experts that allowed ready access to, and portability of, ACCESS modules and databases.

**Outline of the scope and benchmarks for ACCESS development**

It was apparent at the outset that in order to meet the key requirements of stakeholders, ACCESS would need to handle a wide range of timescales from the short- to medium-range, and seasonal to climate/climate change. This requirement was in keeping with international developments where there was a clear move towards the so-called ‘seamless prediction’ strategy. For example, the World Climate Research Programme (WCRP) had proposed a new strategic framework, Coordinated Observation and Prediction of the Earth System (COPES), to capitalise on past progress and with the aim of facilitating analysis and prediction of earth system variability and change for use in an increasing range of practical applications of direct relevance, benefit and value to society.

The progress over time of ESMs at that time was best be summarised by the development of the Met Office Hadle Centre for Climate Prediction and Research model as summarised in Fig. 2 (which also shows planned development of HadGEM2 in 2009). A key aspect was the increasing complexity of the model that progressively included the atmosphere, land surface, ocean and sea-ice, aerosols, carbon cycle and atmospheric chemistry. Most numerical weather prediction (NWP) models only included the atmosphere and land surface although ocean (and sea-ice) components had been added for seasonal prediction and tropical cyclone prediction. There was also a growing interest in environmental prediction. Accordingly, some operational centres had already made a move in this direction by implementing an atmospheric chemistry module in the forecast model and extending their data assimilation system to enable assimilation of chemical species. In order to satisfy the requirement for a state-of-the-art system, ACCESS would need to incorporate these complexities.

An important aspect of NWP and seasonal prediction systems is the inclusion of data assimilation. This had seen major developments in the science and implementation of advanced analysis methods, leading to the operational implementation of four-dimensional variational algorithms (4DVAR) and research on Kalman filter and hybrid 4DVAR/Kalman filter assimilation algorithms. These developments provided the capability of assimilating data from a wide range of observation systems, particularly from satellites and extracting increasing levels of information from them, and had resulted in significant improvements in medium-range prediction skill. ACCESS would therefore need to implement similar developments in order to match the high level of performance attained by modelling systems being run by these centres, if it was to be legitimately categorised as a ‘world-class’ system.

The quality of models depends directly on the quality of the representation of physical processes, many of which are not explicitly resolved, but play a key role in the earth system. Testing and validation of models therefore form an
essential component of a modelling system. Such testing is needed, for example to validate physical parametrisations and component modules, and to identify strengths and weaknesses in the system. Detailed testing, including conducting essential runs with new versions of the models, is necessary before the version can be released for general use. Such testing assumes particular importance if ACCESS was to be used by a wide research community for a wide range of applications. Thus development of ACCESS needed to include a comprehensive model evaluation component.

Most applications in natural resource management and climate impacts assessments require spatial resolutions that are much finer than those offered by global scale climate models. Typical requirements are for spatial scales of order 20–50 km (although there are applications to even smaller scales, these require careful and additional considerations such as the need to include detailed microphysics etc). Thus an important consideration in the development of ACCESS was to provide the capacity to downscale model simulations to spatial scales of relevance.

The increasing complexity and resolutions of ESMs place heavy demands on powerful supercomputers and coding developments for new computing architectures. Most organisations running ESMs have recognised the importance of software engineering for the success of their programs. This component, consisting mainly of computing/software engineering experts, is responsible for software engineering maintenance and development of models and data management tools. It also develops and maintains other aspects such as source code, build and run procedures, porting of codes to different platforms (an ACCESS stakeholder requirement). Its task is to enable scientists to run different components of the ESM without a significant learning curve. Another important requirement is the ability to generate and display a wide range of diagnostics from model output. This is a specialised task that requires expertise in developing graphical and visualisation packages. A strong infrastructure group of software and graphics experts was therefore an important requirement in the development of ACCESS.

In summary, bearing in mind the above considerations, the following outcomes were sought from the development
including ensembles at short-to-medium range (b) numerical model based prediction of the atmosphere and ocean at short-to-medium range and seasonal timescales; and (c) numerical simulation of the coupled atmosphere, ocean and land surface/carbon cycle, aerosols and interactive chemistry on interannual and climate/climate change timescales.

- CSIRO requirements to meet existing commitments and to conduct research in climate/climate change science (and related weather and air quality science) would be substantially enhanced and supported within an ACCESS framework leading to state-of-the-art capability in (a) Australian region climate simulation of the atmosphere, land surface and ocean; (b) application of high quality simulation to specific downscaling applications in natural resource management and in climate impact assessments; and (c) contributing reliable policy-relevant projections of climate change.

- University research in earth system science, computing science and numerical techniques would be substantially enhanced through a partnership with the Bureau and CSIRO that realised a community earth system modelling capability that was flexible and portable.

- Leading research/development and the application of coupled models was evolving towards global environmental monitoring; ACCESS would provide a framework for Australian participation in these programs.

- Wider Australian development of key components in ACCESS such as physical parametrisations and detailed evaluations would result in substantial personnel resources above and beyond the then existing aggregate Bureau/CSIRO capability.

- The ACCESS strategy would result in a highly functional and robust IT infrastructure and in particular supercomputing, data management and high quality diagnostics capabilities.

- Establishment of comprehensive observational data bases and analyses to support consistent ground truth validation of both component models and of the fully integrated coupled systems.

It was noted that ACCESS would need to maintain close contacts with programs of major international organisations such as the World Climate Research Programmes (WCRP) Working Group on Numerical Experimentation (WGNE), Working Group on Coupled Modelling (WGCM), CLIVAR, GEWEX, and the International Geosphere Biosphere Programmes (IGBP) Analysis, Integration and Modelling of the Earth System (AIMES). These two programmes (WCRP and IGBP) play an important role in defining the future directions in earth system modelling and could provide useful guidance for ACCESS.

Finally it was emphasised that the release of ACCESS would have to be accompanied by a significant rationalisation of activities at the Bureau and CSIRO in order to avoid the then existing duplication of effort. A significant movement towards such a rationalisation was made in September 2007.
through the setting up of the Centre for Australian Weather and Climate Research (CAWCR)—a partnership between CSIRO and the Bureau of Meteorology.

**Options for system development with preferred option and reasons for the preference**

Three possible options were considered for the development of ACCESS:

1. develop a new system from scratch;
2. import a well developed complete ESM from an overseas institution; or
3. use and adapt components existing in Australia, and import components that were not adequately developed in Australia.

Option one would have required substantially more time and effort than either of options two or three and could only have been justified if there were very strong scientific or technical reasons for doing so. Given that development of modules, locally or those available overseas, was already based on sound scientific and technical principals, there was little justification for choosing option one.

Importing a complete state-of-the-art ESM from a well established centre appeared to be an attractive option as it would have provided an excellent and quick starting point for ACCESS. As noted earlier, ESMs had been developed and were being used at a number of overseas centres which were willing to provide their complete systems for implementation in Australia and to provide scientific and technical advice. Of these, the Met Office was one of the few centres that used a unified framework for a wide range of applications such as operational NWP (including high-resolution mesoscale modelling), seasonal prediction and climate/climate change studies. It was also the only centre that had developed and operationally implemented an advanced 4DVAR data assimilation system and therefore came closest to satisfying the range of NWP and seasonal prediction requirements for ACCESS.

Option two had the advantage that it would have enabled ACCESS to ‘leapfrog’ into a competitive position without having to go through the slow and demanding process of model development. However this approach came with a number of undesirable aspects—

- The ‘black box’ approach, while seeming to be attractive, had a significant learning curve associated with it.
- A requirement for a successful modelling team is a close understanding of the science and familiarity with the code. The required level of familiarity can be gained proactively, through developing the underlying algorithms and, subsequently code, or reactively, in response to the identification of particular model error/limitations as they arise. The latter approach is usually a very time-consuming process, because it lacks a conceptual ‘big picture’ of the system as a whole.

Importing a complete ESM would necessarily initially place ACCESS developers in a reactive role, with the risk that the putative time-savings associated with this option would not eventuate.

- An undesirable aspect of importing the full ESM was that, at least initially, Australian scientists would mainly be playing a subordinate role to the parent centre, with the main developments still happening at the developing centre, possibly with substantial time delays before any changes/improvements were passed on to other users.
- There could be restrictions on institutions outside ACCESS using the imported ESM.

Consultations with a large number of scientists in the Bureau, CSIRO and the universities showed a strong majority view that ACCESS should not import the complete ESM. There was support for importing modules where those available locally were not in the state-of-the-art category, or had not been developed. It was therefore clear that option two should only be considered if component modules developed and available in Australia were considered unsuitable, based on scientific considerations.

Option three was therefore the preferred option for ACCESS. The advantages of an in-house effort (compared to option two) were that it would provide the opportunity of a much richer and more vigorous scientific program that would come with having a group of scientists who intimately understood the model. The synergy between this group and the other scientists who analyse and apply the model would have strong benefits for Australian climate science. Such a model could also provide a major focal point for collaboration with the universities.

Accordingly, a careful analysis was undertaken to explore the availability and scientific status of modules developed in Australia in providing scientific justification for the selections made for ACCESS. The following sections explore the availability and scientific status of available component modules, and provide justification for the selections made for ACCESS.

**The atmospheric module**

(a) The atmospheric model

The choice of atmospheric model to be used for ACCESS eventually resulted in a recommendation that had major implications for modelling at the Bureau and CSIRO. As such the discussion here is much more detailed; the choice for the remaining modules for ACCESS did not have such major implications for modelling and only a brief discussion will therefore be given.

(i) Option one

The commonly used dynamical cores for atmospheric models were and still are based on two approaches, namely spectral and finite difference. The spectral approach is attractive as it provides accurate solutions to the governing equations in terms of phase and amplitude properties, and had been the most commonly used approach in both climate/climate change modelling and NWP in Australia
and overseas. However, there was increasing interest in
finite difference approaches on the grounds that: (i) it is
possible to implement algorithms that conserve mass
(using the finite volume approach, for example); (ii) it is
possible to use the same grid for the atmosphere and ocean
models, although this was rarely used as ocean models
had increasingly adapted bipolar or tripolar grids; and (iii)
the finite difference approach allows unification for global
and limited area applications. There had however been no
definitive comparisons between the two approaches that
would allow an objective decision to be made for choosing
between the two formulations. Indeed a number of centres,
for example the US Geophysical Fluid Dynamics Laboratory
(GFDL) and National Center for Atmospheric Research
(NCAR), allowed both cores within their ESM (although
both centres had moved to the finite difference versions for
most of their work).

There were three dynamical cores available locally
for global modelling in Australia, namely the Bureau
Atmospheric Model (BAM) spectral core, the CSIRO Mk3
(and successors) spectral core and the CSIRO conformal-
cubic (CCAM) core. Of the two spectral models the key
difference in the two formulations was in their practical
performance. BAM had a clear advantage on this aspect.
BAM had a highly modular structure with a general interface
between the dynamics and physics that allowed the physics
to be applied to global, regional and single-column models
with different grid structures. Both semi-implicit Eulerian
and semi-implicit semi-Lagrangian advection options
were available, and adjoint and tangent linear models had
been developed and used in global ensemble prediction.
The BAM dynamical core and dynamics/physics interface
provided an easier path towards satisfying the requirements
of global modelling (see below) for both organisations.
The CCAM core had a number of attractive features such
as: (i) no polar problem which is an undesirable feature of
most finite-difference models; (ii) it could be readily used for
global and regional modelling; and (iii) both semi-implicit
Eulerian and semi-implicit semi-Lagrangian advection options
had already been implemented. Thus the CCAM
core, when fully developed to include detailed physics and
data assimilation, could also have satisfied the longer-term
requirements for ACCESS.

The choice of a dynamical core for ACCESS needed
to ensure that both the short and longer-term ‘business
continuity’ requirements of the main stakeholders were
satisfied. These requirements could broadly be summarised
as: (i) operational commitments for the Bureau that relied
heavily on BAM; (ii) DCCEE commitments for CSIRO
involving provision of climate change projections and
including regional downscaling; and (iii) university
requirements including regional downscaling. An option
that could satisfy these requirements in the short-term (~3
years) was for ACCESS to start with two dynamical cores,
namely the BAM and CCAM cores. A possible strategy in
adequately handling the two-core strategy was to include
the CCAM core within the BAM framework that had a
significant supporting infrastructure. This approach was
attractive because it would enable detailed comparison
of the performance of the two cores when they were fully
developed and when the main modules of ACCESS had
been coupled; the eventual choice of a single core could then
be made on the basis of performance.

(ii) Option two
A key aim of ACCESS was to have a common system for
both global and limited area modelling in moving towards
a national approach to model development. A unified global
and limited area system within the BAM spectral core would
have required a major effort that was not warranted. The
CCAM core could have provided the unified system but such
a system could only be acceptable once all ACCESS modules
including data assimilation had been developed and coupled,
and the full system had been extensively verified.

A key recommendation for ACCESS atmospheric data
assimilation was to import the Met Office’s variational data
assimilation system (VAR) which included 3DVAR and
4DVAR (see below). This, together with the associated data
handling software capabilities, could have been adapted to
work with the global spectral core for which the tangent
linear and adjoint models had already been developed as
essential components of the global ensemble prediction
system. However the use of the variational analysis software
with the CCAM core would have required tangent linear and
adjoint models to be developed for this system. Although the
procedures for developing these were well developed and
understood they are highly resource dependent and time
consuming.

One possible solution to the issues of model unification
and additional developments related to implementation of
the Met Office VAR system was to import the Met Office
Unified Atmospheric model (to be referred to as the UM)
together with VAR. The UM is the atmospheric component
of HadGEM (Hadley Centre Global Environmental Model)
which is the fully coupled ESM developed at the Met Office.
The individual components and the fully coupled model had
been extensively tested and the results documented in
technical reports and journal publications. HadGEM version
one (HadGEM1) was used for the Met Office’s contributions
to the IPCC Fourth Assessment and the European Union
ENSEMBLES project (www.ensembles-eu.org) and a later
version (HadGEM2) was being developed for the IPCC
Fifth Assessment (AR5) runs. It was being used as a basis
for the development of a higher resolution coupled model
known as HiGEM, in a project sponsored by the UK National
Environmental Research Council (NERC) and led by the
University of Reading. The collaborative project involved
several universities and was aimed at delivering a community
model as well as helping coordinate the understanding and
improvement of the model by a wider user community,
particularly regarding its systematic errors. Thus there were
considerable advantages in ACCESS establishing close
The above considerations led to the following options for the dynamical core, namely:

- **Option one.** ACCESS should initially start with two dynamical cores, the BAM and CCAM cores; the preferred eventual choice of a single core should be made through detailed comparison of relative performance when all modules of ACCESS have been coupled.

- **Option two.** ACCESS should import HadGAM1 (UM) to provide the initial atmospheric model for ACCESS. Following detailed discussions option two was accepted as the dynamical core to be used in ACCESS.

(b) **Data assimilation**

There have been major developments in the past twenty-years in the science and implementation of analysis methods, leading to the operational implementation of four-dimensional variational algorithms (4DVAR) and research on Kalman filter assimilation algorithms (see Kalnay 2002 and references therein). These developments provide the capability of assimilating data from a wide range of observation systems, and particularly from satellites, and have resulted in significant improvements in short- and medium-range weather prediction.

The main expertise in atmospheric data assimilation in Australia has existed at the Bureau where it has formed an essential component of the operational NWP systems. The pre-ACCESS long-term strategy for the Bureau assimilation module was based on the development, within the then operationally used Generalised Statistical Interpolation (GenSI) scheme, of an Ensemble Kalman Filter (EnKF) formulation similar to that being used in Canada. The strategy was chosen due to the advantages of evolving from a known system and the lack of resources available to support a 4DVAR strategy, coupled to an assessment that the EnKF may in fact be competitive and perhaps advantageous relative to 4DVAR on the mesoscale.

There were advantages with the EnKF based approach, such as:

- a solid local capability and knowledge base of the algorithms; and
- it represented an evolutionary strategy relative to the then existing capability.

There were, however some major concerns with this approach, such as:

- a large development gap existed between GenSI/EnKF and other competing 4DVAR systems particularly in regard to the associated systems for incorporating remotely sensed observations and tuning assimilation parameters;
- more resources at operational NWP centres were being devoted to variational techniques than to ensemble approaches, which would potentially exacerbate the slow developments of EnKF science in the operational context (note that this situation has changed recently with a move towards hybrid variational/ensemble formulations);
- EnKF had not yet been demonstrated to be a successful competitor with 4DVAR at either the synoptic or mesoscale, although significant progress had been reported. It should be noted that a concern with regard to 4DVAR was potential unsuitability at the mesoscale associated with the difficulty in developing tangent linear and adjoint codes adequate for highly non-linear regimes at the mesoscale; and
- the algorithmic incompatibility of the GenSI system relative
to overseas operational 3D/4DVAR systems mitigated against inclusion of developments from other centres.

The primary concern regarding a continuation of the then existing strategy was that at least as many resources would have been required to maintain and enhance the system algorithms; additionally there were significant resource requirements to bridge the infrastructure gap necessary to support assimilation.

Thus the scenario that was most likely to deliver the best NWP system for ACCESS was that of close and ongoing collaboration with an external agency. This would provide the scope to facilitate a rapid catch-up in both assimilation and modelling. As was noted earlier the Met Office was the only major centre that had developed a unified framework for a wide range of applications such as operational NWP, seasonal prediction and climate/climate-change studies. It had developed and operationally implemented an advanced data assimilation system based on 4DVAR. The plans at the Met Office in data assimilation were very comprehensive with respect to continuing development of global 4DVAR and limited area 4DVAR for mesoscale modelling. The use of ever increasing amounts of remotely sensed data was planned with significant research and development on the next generation of sounders, the use of GPS occultations, ground based GPS, Doppler wind lidar, and cloud affected IR radiances and precipitation radar.

The essential requirements for the VAR system, the tangent linear and adjoint models, had already been implemented in the Bureau’s global model (BAM) for application to ensemble prediction. Thus it would be feasible to use components of the UK VAR system such as observational handling, the minimisation package, and generation of increments on model grid in conjunction with BAM. Discussions with the then head of Data Assimilation Group at the Met Office (Andrew Lorenc) indicated that the Met Office VAR system could be ported to BAM and that it could be made available (Andrew Lorenc) indicated that the Met Office VAR system could be ported to BAM and that it could be made available to ACCESS for research and operational purposes following signing of a formal agreement.

Import of the Met Office VAR system (Rawlins et al. 2007) could result in the following highly desirable outcomes.

- It was both possible and workable provided ongoing exchange of staff was strongly supported.
- It would produce a better overall system in the long-term than would be achieved from any of the alternative options.
- It would rapidly introduce world’s best practice to local NWP.
- The science of the Met Office 4DVAR was well understood within BMRC.

It was however noted that the approach would:

- still require significant local expertise in assimilation to adapt the system for local use (covariance modelling, quality control etc.);
- continue to require investigations into EnKF behaviour, albeit with some modification;
- require resources for the development of linearisation and adjoint versions of CCAM dynamical core, and of any locally developed parameterizations; and
- require the external partner to have similar aims and goals due to the coupling between the assimilation system and the physics parameterizations introduced by 4DVAR.

On balance it was concluded that Met Office VAR option had considerable merit and led to the following recommendation—the Met Office 4DVAR scheme should be imported to form the atmospheric data assimilation module in ACCESS. Work on EnKF formulation should be continued to provide an extension to the VAR scheme.

Ocean and sea-ice modules

(a) Core models

The Australian Climate Ocean Model (AusCOM) (Roberts et al. 2007) is a coupled ocean and sea-ice model aimed to serve the Australian climate sciences community (including the Bureau of Meteorology, CSIRO and Australian universities) for ocean climate research and applications. AusCOM in its current form (Bi and Marsland 2010) comprises the NOAA/Geophysical Fluid Dynamics Laboratory Modular Ocean Model version 4.1 (GFDL MOM4p1), and the Los Alamos National Laboratory Sea Ice Model version 4.0 (LANL CICE4.0). The move to MOM4 in the current version (now referred to as ACCESS-OM) provided a natural extension to the use of the older MOM2 ocean code in the original version.

MOM4 is a community code, with contributions by many scientists from collaborating institutions around the world, including researchers at CSIRO Marine and Atmospheric Research and the Bureau. A description of the MOM4 framework and elements can be found in the technical report (Griffies et al. 2004). A detailed introduction to the theoretical aspects of the oceanic physics, dynamics and various parameterizations realised in the model numerics can be found in Griffies (2004). Use of the MOM4 as the ACCESS ocean module had a number of advantages, namely: (i) MOM was widely recognised as a leading world-class ocean model; (ii) there was and still is a long history of MOM usage in Australia with associated development of inhouse expertise; (iii) synergy would be maintained with the other major CAWCR ocean modelling theme, involving BLUElink and associated projects, which focus on eddy-permitting regional to global scale modelling using MOM; and (iv) there had been a long and fruitful history of collaboration between CSIRO, Bureau and GFDL scientists on ocean modelling, for which there was considerable support to continue and enhance.

The original sea-ice model in AusCOM was based on an early version of the Los Alamos Sea Ice Model (CICE) (Hunke and Lipscomb 2008, Hunke 2001, Hunke and Dukowicz 1997). Subsequently, through collaboration with other institutions such as NCAR and UK Met Office, the CICE4.0 release had been largely enhanced in terms of its technical and physical compatibilities with different models. In particular, CICE now supported tripolar grids, and a ‘zero-layer’ thermodynamic parameters...
configuration to allow overlaying of the atmospheric model to calculate the ice surface temperature. Like MOM4, it has been recognised as a state-of-the-art model, and used widely by researchers round the world. For ACCESS it was recommended that the early version used in AusCOM be replaced by the more recent CICE4 version.

In summary MOM4/CICE4 (AusCOM) provided a state-of-the-art ocean sea-ice model with local expertise and international connections and was accepted as the ocean/sea-ice module for ACCESS.

b) Data assimilation
Ocean data assimilation was first used within the Bureau in the POAMA-1 system. The analysis used a single level two-dimensional univariate optimum interpolation based on the system described in Smith et al (1991) and only in situ ocean temperature profiles were assimilated. This system had a number of shortcomings, namely it was univariate, two-dimensional and applied to each level independently, and used pre-specified static covariances.

Under the BLUElink project a new ocean data assimilation system, the Bluelink Ocean Data Assimilation System (BODAS), had been developed to extend the functionality of the Smith scheme. BODAS is a stand-alone code that can be readily applied to different models and different applications. The scheme, described by Oke et al. (2005, 2008), is based on an Ensemble Optimal Interpolation (EnOI; Oke et al. 2002) scheme that is underpinned by a time invariant ensemble of model anomalies. BODAS had been used in a near-global eddy-resolving model for ocean reanalysis (Schiller et al. 2008) and operational forecasting (Brassington et al. 2007), a global coarse resolution model for seasonal prediction (Yin et al. 2011), and a series of high-resolution coastal models (Oke et al. 2009).

There were plans for the extension of the BODAS system for seasonal prediction. Firstly an extended version (eBODAS) that calculates flow dependent error covariances using an evolving forecast ensemble (Alves and Robert 2005) was being developed and plans were to subsequently extend it to a full ensemble Kalman filter. BODAS and its planned extensions into the extended versions (eBODAS and ensemble Kalman filter) provided a flexible system that could be applied to any fixed coordinate ocean model and formed a good starting point for the ocean data assimilation component of ACCESS.

Hydrology/carbon cycle modules

(a) Terrestrial
Following discussions between experts in the field, there was agreement that local terrestrial biosphere models (TBMs) were as good as (and in some areas ahead of) the state-of-the-art models, although they had not been tested in climate model environments to the same extent as schemes in other climate models. Several Australian TBMs had been developed but were converging in the CSIRO Atmospheric Biosphere Land Exchange (CABLE) model. There was a strong recommendation for ACCESS backing and investing in CABLE and its future development.

CABLE is a model of biosphere-atmosphere exchange allowing for interaction between microclimate, plant physiology and hydrology (Kowalczyk et al. 2006, Wang et al. 2011) and includes features that are represented in similar state-of-the-art models. An important desirable feature of CABLE was that its development represented the combined work of a number of Australian scientists and was being seen as the community TBM. This would readily allow continuing development of the model to include new scientific developments.

CABLE did not include dynamic vegetation and a recommendation was to import this component. It was generally agreed that the Lund-Potsdam-Jena (LPJ, Sitch et al. 2003) was the most appropriate model as it was freely available, well coded and documented, and was being used in a number of ESMs. It was also noted that the eventual choice of the dynamic vegetation to be used for ACCESS was still an open area and the initial recommendation to use LPJ could be changed to the use of a more appropriate model at a later stage of ACCESS development.

<table>
<thead>
<tr>
<th>Module</th>
<th>Name</th>
<th>Source</th>
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<tbody>
<tr>
<td>Atmosphere</td>
<td>Met Office Unified Model (UM)</td>
<td>Met Office</td>
</tr>
<tr>
<td>Ocean</td>
<td>Modular Ocean Model version 4 (MOM4)</td>
<td>NOAA Geophysical Fluid Dynamics Laboratory</td>
</tr>
<tr>
<td>Sea-ice</td>
<td>The Los Alamos Sea Ice Model version 4 (CICE4)</td>
<td>DoE Los Alamos National Laboratory</td>
</tr>
<tr>
<td>Land surface/carbon cycle</td>
<td>The CSIRO Atmosphere Biosphere Land Exchange model (CABLE)</td>
<td>CSIRO</td>
</tr>
<tr>
<td>Chemistry and aerosols</td>
<td>United Kingdom Chemistry and Aerosol model (UKCA)</td>
<td>Met Office, Leeds and Cambridge universities</td>
</tr>
<tr>
<td>Data Assimilation (atmosphere)</td>
<td>4-dimensional variational assimilation (4DVAR)</td>
<td>Met Office</td>
</tr>
<tr>
<td>Data Assimilation (ocean)</td>
<td>Ensemble Kalman Filter</td>
<td>Bureau/CSIRO</td>
</tr>
<tr>
<td>Coupler</td>
<td>Ocean Atmosphere Sea Ice Soil (OASIS)</td>
<td>CERFACS (Centre Européen de Recherche et de Formation Avancée en Calcul Scientifique)</td>
</tr>
</tbody>
</table>

Table 1. Modules of the ACCESS ESM
(b) Ocean

The view of relevant experts in Australia was that the Matear carbon cycle model (Matear et al. 2008) was as comprehensive as the models used elsewhere. The model includes a simple biogeochemical (BGC) component that is linked to a simple marine ecosystem model which includes nitrate, phytoplankton, zooplankton, and detritus compartments. Some future developments that had been flagged include extending the ecosystem based carbon model to incorporate multiple phytoplankton functional groups and implementing additional elemental cycles such as iron which is an important driver of carbon cycle dynamics.

Thus the locally developed Matear model provided a good starting point for ACCESS upon which future developments of the ocean biogeochemistry could be based.

(c) Data assimilation

Soil moisture can have a significant impact on near surface temperatures and humidity, low clouds and precipitation by influencing the exchange of heat between the land surface and the atmosphere (Drusch and Viterbo 2007, Zheng and Frederiksen 2003, Fisher et al. 2007). Furthermore a number of new space-borne systems operating at microwave frequencies had been developed that provide a more direct retrieval of soil moisture. Examples of the systems include the Advanced Scatterometer (ASCAT), Soil Moisture and Ocean Salinity (SMOS), the Advanced Microwave Scanning Radiometer – Earth Observing System (AMSR-E). As a result there was increasing activity in developing systems to assimilate data from these instruments.

At the time of the early ACCESS planning stage there was some land-surface data assimilation work being conducted within Australia. BMRC had developed and implemented a soil moisture nudging scheme in its operational NWP systems and CSIRO had expertise in parameter fitting for large-scale models. Work on land-surface data assimilation was being conducted by groups at Melbourne, Monash, and Newcastle universities.

As land-surface data assimilation is closely related to the physical and numerical formulations used in the land-surface scheme itself, it was not feasible to directly import a system from overseas for ACCESS. Hence the recommendation was for ACCESS to make a start in developing an assimilation capability in CABLE based on ongoing work at some leading centres. Experience with atmospheric data assimilation systems however showed that this capability should use a framework that allows for the ready incorporation of developments from elsewhere. It would therefore be important for ACCESS to establish close contacts, and collaborations with international organisations that were active in this area.

Atmospheric chemistry

Although atmospheric chemistry modules had been developed at a number of centres that run ESMs, they had not been included in extended climate runs because of the associated high computing cost. Offline runs of the chemistry model were being used to develop climatology of emissions that were read in during extended climate runs. The most widely used chemistry model was MOZART (Model of Ozone and Related Tracers, Brasseur et al. 1998) which is a stand-alone model that was developed jointly by MPI, NCAR and GFDL. MOZART is a community model that is publicly available for scientific and policy-related issues, and is designed to run on almost any computer platform. The Met Office, in collaboration with Leeds and Cambridge universities, was also developing the UK Chemistry and Aerosols model (UKCA, Abraham et al. 2012) with the aim of including it within HadGAM.

The initial recommendation was for ACCESS to import MOZART in order to gain expertise with running the model in a stand-alone mode and to eventually implement simplifications to enable it to be run interactively.

Subsequent to the initial recommendation, and following the decision for ACCESS to use the UM and VAR systems from the Met Office, it was decided to change this recommendation and use UKCA as the ACCESS chemistry module instead. The main advantages of using UKCA (Hurley, private communications) were: (i) the option was better suited to available resources; (ii) there was less risk associated as a pre-connected inline version would be available; and (iii) the option would provide increased scope for collaboration with the Met Office and Leeds/Cambridge universities for joint future developments.

Modelling infrastructure

A key objective of ACCESS was the development of an earth system modelling and assimilation system that would be available for use by a wide community of researchers. The system would need a complex technical infrastructure that could provide the capability to couple all components together in a scientifically robust manner but also ensure computational efficiency and ability to run on a variety of computing platforms. The development of such an infrastructure by a well resourced software engineering team had been emphasised by all major centres running such systems. It was further noted that infrastructure support needed to be provided by professional software engineering personnel and that design of infrastructure was crucial before any major developments commenced.

Substantial efforts had been expended at the major centres running ESMs in developing the complex infrastructure needed to: (i) assemble earth system coupled models using a coupler; (ii) launch/monitor complex simulations including ensembles; (iii) access, analyse and share results across a wide community; and (iv) define and promote technical and scientific standards for earth system modelling.

A key message from the major ESM centres was that ACCESS should import existing systems rather than develop one from scratch. The OASIS (Ocean Atmosphere Sea Ice Soil) coupler developed under the European PRISM...
Puri: ACCESS: Scientific justification and options for system development

(Program for Integrated Earth System Modelling) project had been used for a number of years at the Bureau and CSIRO and was therefore the recommended option for use in ACCESS. Apart from the existing local expertise OASIS had a number of features that made it a suitable coupler for ACCESS. It provided a robust and well supported facility to couple different modules and to allow: (i) the realisation of coupled simulations on different types of platforms at a minimal cost by providing the capability to communicate required fields between different modules that use different grids and resolutions; (ii) the testing of different coupling algorithms (e.g. time strategy or interpolation methods); and (iii) an objective intercomparison of coupled models by changing some or all component models.

Accepted options for ACCESS development

Table 1 shows the final agreed components of ACCESS and the source of individual modules. Figure 5 shows a schematic of the proposed fully coupled system. All subsequent work has been aimed at completing development of the system depicted in the schematic. Note that the ocean and sea-ice modules are coupled to the atmospheric model via the OASIS coupler as the modules use different grids and resolutions; the land-surface and chemistry modules on the other hand are coupled directly to the atmospheric model as they are on the same grid.

The fully coupled system depicted in Fig. 5 satisfies the design criteria for a seamless prediction system in the sense that the atmospheric and land-surface modules including data assimilation define the uncoupled NWP component while adding the ocean/sea-ice (and chemistry) modules define the seasonal prediction and climate projection system and so on.

ACCESS implementation—a brief summary

As noted earlier, the decisions which involved significant changes in the modelling activities at the Bureau and CSIRO, were the use of the Met Office atmospheric model (UM) and the Met Office data assimilation (VAR) system in the development of ACCESS. It was recognized that the Met Office systems, together with components developed at the Bureau and CSIRO, offered considerable advantages for applications to both weather prediction and climate/climate change. The atmospheric models used at the Met Office for operational NWP and climate modelling (including regional climate modelling) were all derived from the Unified Model (UM) system. Some of the key features of the model include: (i) use of governing equations that are non-hydrostatic; (ii) use of a semi-implicit/semi-Lagrangian scheme to solve the governing equations; (iii) design of the dynamical core that includes conservation of mass, mass-weighted potential temperature and moisture, and angular momentum; and
Operational implementation of the ACCESS NWP system started in 2006 and with some key milestones. Significant progress has been made since development laid out in the recommendations made in the Project Plan. Development of ACCESS has progressed along the lines of interactions to facilitate the use and further development of existing collaborations between CAWCR and a number of Australian universities and plans are to enhance these are existing collaborations between CAWCR and a number of Australian universities and plans are to enhance these sub-licence with the Met Office through the Bureau. There Some key Australian universities have also signed a similar scheme, tropical cyclone prediction, and observation data increases as CAWCR scientists develop increasing familiarity handling for data assimilation. These contributions will increase as CAWCR scientists develop increasing familiarity and expertise with the Met Office systems.

The Met Office modules (UM, VAR, UKCA) have been obtained under a research licence signed between the Met Office, Bureau and CSIRO that allows use of the software for research and operational use. The licence was accompanied by a separate research plan that defined projects for collaboration between CAWCR and Met Office scientists. The initial areas of collaboration included model development (numerics and physics), model evaluation particularly in the Australian/Pacific region where CAWCR scientists would play a leading role, prediction and understanding of tropical cyclone and tropical phenomena such as monsoons and the Madden-Julian Oscillation (MJO), regional climate modelling, coupling development/issues, and software development. Under these projects CAWCR scientists directly contribute to the development of the modelling systems. Significant progress has already been made by CAWCR scientists in a number of areas including improvements to the radiation scheme, tropical cyclone prediction, and observation data handling for data assimilation. These contributions will increase as CAWCR scientists develop increasing familiarity and expertise with the Met Office systems.

Some key Australian universities have also signed a similar sub-licence with the Met Office through the Bureau. There are existing collaborations between CAWCR and a number of Australian universities and plans are to enhance these interactions to facilitate the use and further development of ACCESS.

Development of ACCESS has progressed along the lines laid out in the recommendations made in the Project Plan. Significant progress has been made since development started in 2006 and with some key milestones.

- Operational implementation of the ACCESS NWP system including assimilation of significantly increased number of satellite sounders. Implementation in September 2009 has been marked by a significantly increased skill relative to the previous operational systems, and the system performance is now similar to other major operational centres.
- Successful assembly of fully coupled ACCESS and detailed testing of the coupled system. Subsequently the core CMIP5 simulations have been completed with two configurations of ACCESS, one using the Met Office MOSES land surface and a second one using CABLE and upgraded physical parametrisations. Model output data from both configurations has been published on the Earth System Grid (ESG) and will form an important component of the Australian contribution to CMIP5 and the IPCC Fifth Assessment. Preliminary assessment of ACCESS runs show encouraging performance of the system with ACCESS falling in the top tier of the climate models.
- Development of high-resolution (1.5 km) version for severe weather prediction, including radar data assimilation which has shown encouraging skill in predicting heavy rainfall events.
- Implementation in research mode of the ACCESS ensemble prediction system.
- Commencement of work on using the ACCESS coupled system for seasonal prediction.
- Progress in the development of ACCESS infrastructure. Examples include successful porting to both Bureau and National Computational Infrastructure’s (NCI) supercomputers; development, in collaboration with the Centre of Excellence (CoE) for Climate System Science, of infrastructure to enable ready usage by university researchers; and setting up of a unified repository based at NCI.

The ACCESS NWP implementation and evaluation of its performance has been reported in Puri et al. (2013) and a number of manuscripts describing the assembly of the fully coupled ACCESS and evaluation of the CMIP5/AR5 runs are in preparation.

The timeline for the development of ACCESS set by the primary stakeholders was tight and required dedicated teamwork to perform the necessary model building, testing and evaluation tasks. Operational implementation of the ACCESS NWP systems and completion and publication of the core CMIP5 runs with the coupled ACCESS marked major milestones for the development and fulfilment of two key requirements of the supervisory committee.

A pleasing aspect of the development is the increasing use of ACCESS by a wider group of researchers, including experimentation with physical parametrisations (particularly through the use of the lightweight and portable ‘single-column model’), tropical cyclone studies, impact of enhanced stratospheric resolution, use of idealised limited area version of ACCESS, and studies on atmospheric tracer mass conservation in the UM. This trend should accelerate with further development of the ACCESS infrastructure including proper version control of all ACCESS modules that are supported by software engineering experts.

**Conclusion**

The design of ACCESS provides a platform that has the flexibility needed to implement major upgrades and
new applications. The results obtained from the initial operational implementation, including major performance gains relative to the Bureau’s previously operational systems (GASP and the Limited Area Prediction System, LAPS, Puri et al. 1998), provide considerable confidence that the future development of the system will enable the Bureau to provide short-to-medium range and seasonal forecasts with continually improving degree of precision and reliability. Similarly evaluation of the coupled ACCESS model runs indicates that the system is already providing simulations that are superior to the previously used Australian coupled models and lie within the top tier of the international climate models.

A key aspect of the ACCESS development is fostering of national and international collaborations. Substantial collaborations have been established with key international agencies such as the Met Office, GFDL, ECMWF, Korea Meteorological Administration (KMA) and the New Zealand National Institute of Water and Atmospheric Research (NIWA). These collaborations are likely to increase and will contribute to the future improvements of the system. Nationally, collaborations with universities are increasing and an increasing number of university scientists are starting to use ACCESS for their own research and for collaborative research with CAWCR scientists. The links with the universities will receive a significant boost as the new Centre of Excellence for Climate System Science becomes fully operational. However the infrastructure underlying ACCESS will need to be significantly enhanced to make the system more portable and easy to use by university researchers. Work on this aspect has already commenced with significant CoE support.

Finally, recognising the first ACCESS Blueprint and Project Plan were developed in 2005, a new blueprint for ACCESS modelling covering the period 2012–2017 has been developed. The new blueprint is aimed at: (i) informing the respective agencies of the national benefits accruing from future developments in ACCESS; (ii) defining the underlying science and technical requirements and associated applications; (iii) articulating the resource requirements for its realisation, taking into consideration future developments in earth system modelling; and (iv) the need to accommodate the requirements of the primary stakeholders, namely the Bureau of Meteorology, CSIRO and the university community.

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