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CSIRO

Our Ref: 09/339

Committee Secretary
Standing Committee on Industry, Science and Innovation
PO Box 6021
House of Representatives
Parliament House
Canberra ACT 2600

22 April 2009

Dear Secretary

Re: Inquiry into long-term meteorological forecasting in Australia

We thank you for the opportunity to provide comments on the above inquiry. Our detailed responses to the Terms of Reference can be found in the attached submission.

CSIRO's world-class strength in climate and atmospheric science coupled with the strategic research and operational roles of the Bureau of Meteorology provides the core of Australia's capability in meteorological forecasting and places both agencies at the centre of the National Innovation System on this topic. Delivering a world-class weather and climate modelling capability is a central plank of CSIRO's strategic plan. CSIRO is pursuing this goal through its jointly managed research partnership with the Bureau of Meteorology, known as the Centre for Australian Weather and Climate Research (CAWCR).

Through CAWCR, Australia is now building the next generation weather, climate and earth system simulation capability, called ACCESS (the Australian Community Climate and Earth System Simulator). ACCESS is already delivering short-term weather forecasts with greatly improved skill over the current system.

Further development of this capability will provide significant advances in seasonal forecasting skill and resolution but, as we outline in our submission, will require significant further investment in supercomputing infrastructure, observation acquisition and assimilation and scientific expertise.

If you have any queries regarding the content of our submission or would like any further information, please do not hesitate to contact Dr Kilian Perrem at CSIRO Government and International (kilian.perrem@csiro.au; 02 6276 6480).

Yours sincerely

Andrew Johnson
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CSIRO Submission 09/339

Inquiry into long-term meteorological forecasting in Australia

The House of Representatives Standing Committee on Industry, Science and Innovation

April 2009

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Executive Summary

Meteorological forecasting and climate modelling is important to Australia's economic, environmental and social well-being and prosperity. Australia's location and size exposes it to a variety of weather extremes such as heatwaves, bushfires, cyclones, floods and storms. Decisions from planting crops through to emergency management procedures and systems, rely on an ability to forecast weather at a variety of time scales from hours to days, across seasons and on even longer timescales.

Australia also is particularly vulnerable to the impacts of climate change. Climate change is expected to result in declining rainfall and increased frequency of drier and warmer droughts, at least for the southern part of the continent, and the risk of more intense and frequent extreme events such as heavy rainfall and tropical cyclones in the north. These changes will affect terrestrial and marine ecosystems and industries. Forecasting those effects will enable informed planning of responses to them.

Australia is an isolated continent in the Southern Hemisphere. We have had to develop our own climate modelling and forecasting capability, underpinned by a world-class meteorological science developed over many decades. Basic and applied forecasting research and development has been led by the Bureau of Meteorology and CSIRO, in concert with key international partners – in particular the Hadley Centre of the United Kingdom Meteorological Office (UKMO) which is one of the world's pre-eminent weather and climate modelling centres.

CSIRO and the Bureau of Meteorology jointly manage their atmosphere, weather and climate research capability through the Centre for Australian Weather and Climate Research (CAWCR). CAWCR builds critical mass in weather and climate research capability in Australia and provides a single "point of entry" to Australia's nationally-funded R&D capability in weather and climate prediction. This formal collaboration between CSIRO and the Bureau is a key element of Australia's future research and development capability in meteorological forecasting. CAWCR also continues the essential nexus between research and operations that has been a hallmark of the Bureau of Meteorology's successful approach to meteorological forecasting.

Key Points

Long-term meteorological forecasting (hereafter ‘season or seasonal forecasting’) is interpreted in this submission to comprise primarily forecasting weather from one to several months in advance. We use the term ‘seasonal forecasts’ to refer to this interval.

The key points of the submission against the five Terms of Reference are summarised as follows:

TOR 1: The efficacy of current climate modelling methods and techniques and long-term meteorological prediction systems

(1) Seasonal forecasting for Australia is provided predominantly by the Bureau of Meteorology. Most operational forecasts are based on statistical forecast methods that have been used for over two decades. Some new, experimental dynamic forecasts show improved forecast skill and are expected to replace statistical forecasts in the near future.

TOR 2: Innovation in long-term meteorological forecasting methods and technology

(2) Existing statistical seasonal forecasts for Australia have reached the summit of their ability. Recent initiatives are focussed on developing next-generation dynamic seasonal prediction models that are expected to be responsive to changing climate conditions. The new world-class systems will require upgraded supercomputer infrastructure, enhanced observational inputs and state-of-the art data assimilation techniques to deliver cutting-edge operational services at improved spatial and temporal resolution.

(3) Australia is building the next generation weather, climate and earth system simulation capability, called ACCESS (the Australian Community Climate and Earth System Simulator). ACCESS will deliver Australia’s short-term weather forecasts, seasonal forecasts, and global and regional multi-decadal climate projections from local to global scales. ACCESS already is delivering short-term weather forecasts with greatly improved skill over the current system. The main needs for more rapid development and deployment of ACCESS are: significant enhancement of supercomputing infrastructure; increased staff capacity; and improved techniques for assimilating observations of the land, air and oceans, especially from satellites.

TOR 3: The impact of accurate measurement of inter-seasonal climate variability on decision-making processes for agricultural production and other sectors such as tourism

(4) Reliable seasonal forecasting has considerable potential to deliver tangible benefits for forward planning and business operations in agriculture and water resources, and other industry and government sectors, and the broader community. Some benefit already exists but would be enhanced through improved seasonal forecasting, clarification and education about how to interpret and apply forecasts appropriately, and therefore, increased user-confidence about what seasonal forecasts do (and don’t) offer.

TOR 4: Potential benefits and applications for emergency response to natural disasters, such as bushfire, flood, cyclone, hail, and tsunami, in Australia and in neighbouring countries

(5) Emergency response management by definition involves reacting to largely unpredictable events. Seasonal forecasting cannot provide prescriptive forecasts of specific events but can improve significantly the expectation of what sort of events (e.g., fire or flood) are most likely for coming seasons. Such forecasts allow strategic planning of response logistics and focus, and provide advance warnings to emergency response groups, industry, and the community about what should be expected for future seasons.

TOR 5: Strategies, systems and research overseas that could contribute to Australia’s innovation in this area

(6) Australia has great dependence on international observation systems, such as satellite data, and benefits considerably from weather and climate forecasting technology developments in other countries. Australia’s next generation forecasting systems are being built from model components mostly developed in the USA, UK or Europe, but enhanced for Australian conditions. National capacity to further develop forecasting technologies is essential, because of Australia’s specific vulnerability to Southern Hemisphere phenomena that are not the focus of most developed nations’ forecasting activities. Continued benefit from international sources substantially rests on continued Australian contributions to global research and development activities.

CSIRO’s expertise in relation to the Inquiry’s Terms of Reference

CSIRO’s world-class strength in climate and atmospheric science coupled with the strategic research and operational roles of the Bureau of Meteorology provides the core of Australia’s capability in meteorological forecasting and places both agencies at the centre of the National Innovation System on this topic.

Delivering a world-class weather and climate modelling capability is a central plank of CSIRO’s strategic plan. CSIRO is pursuing this goal through its jointly managed research partnership with the Bureau of Meteorology – CAWCR.

CAWCR in collaboration with the universities is building the nation’s next generation weather and climate model, called the Australian Community Climate and Earth System Simulator (ACCESS, see Appendix 1). ACCESS will provide Australia with a common simulation system for delivering short-term weather forecasts, seasonal forecasts and longer-term, multi-decadal climate projections. At the core of ACCESS is an atmospheric model developed by the United Kingdom Meteorological Office (UKMO) which is regarded as a world-leading model with state-of-the-art data assimilation.

CSIRO also is developing strategies for adapting to and mitigating the impacts of climate change and climate variability, particularly in the agricultural, urban and water resources sectors. CSIRO’s Climate Adaptation National Research Flagship and Water for a Healthy Country Flagship provide leading applied science in tandem and informed by CSIRO and the Bureau’s meteorological science and products. CSIRO has strong linkages to industry practitioners, policymakers, community leaders and the general research community.

The submission provides an ***introductory preamble*** about meteorological forecasting and ***addresses each of the Terms of Reference***, commenting on the state of the science, significant knowledge gaps and action to address the gaps. Additional information about ***ACCESS*** is provided in Appendix 1.

Introduction

Preamble about meteorological forecasting

Long-term meteorological forecasting (hereafter 'season or seasonal forecasting') is interpreted in this submission to comprise primarily forecasting weather and climate from one to several months in advance. We use the term 'seasonal forecasts' to refer to this interval. We do not comment on short term weather forecasting (hours to a several days) or on climate-scale projections (years to centuries) other than as necessary to provide some context around our comments on seasonal forecasting.

Weather forecasting in general involves gathering empirical observations about past or present conditions that influence weather and using those observations in some way to predict what the weather conditions will be at some future time. Forecasts can be based on statistical interpretations of existing observations ('statistical forecasts') but more usually are based on complex models of the atmosphere, earth surface and ocean that take as input the empirical observations of existing or past conditions. The digestion of observations into the models (termed data assimilation) allows the models to be set up with credible, realistic starting conditions from which to simulate the evolution of weather systems into the future ('dynamic forecasting'). Both statistical and dynamic approaches are in use for seasonal forecasting in Australia.

A key assumption of statistical forecasting is that past weather and climate patterns are sound indicators of what we can expect in future. Climate change challenges this assumption because it is expected that future conditions that affect weather and climate increasingly will depart from past experience. Similarly, unusual events in a given year generally cannot be anticipated well by statistical forecasts unless such unusual events have been experienced before. Dynamic forecasting is more likely to be responsive to climate change and unusual events because the models can assimilate (dynamically) the changing conditions and adjust modelled weather behaviours accordingly. Hence, dynamic seasonal forecasting has the greatest prospect of improving seasonal forecast accuracy.

The models use extensive mathematical calculations based on the laws of physics and require significant supercomputing power to run. They are not perfect representations of the weather system, however, and so do not produce exact forecasts of the future. Hence, every forecast has a degree of uncertainty attached to it. The closeness of forecasts to actual events when reviewed with hindsight is referred to as 'forecast skill'. Forecast skill for both statistical and dynamic forecasts for a given time interval (e.g., daily forecasts) declines as predictions are made further into the future. Hence, forecasts of tomorrow's weather are generally better than forecasts of the weather five days from now. The skill of predictions of general weather over longer intervals (e.g., average weather for a month rather than on a particular day) generally have skill for longer into the future than high resolution (e.g., daily) predictions. Thus, seasonal forecasts tend to involve statements about average conditions over future weeks to months rather than forecasts of specific conditions on particular days in a future season.

The degree of uncertainty attached to a short- and long-term weather forecast increasingly is being quantified by running forecasting models repeatedly with slightly different starting conditions, perhaps based on increasingly recent observation inputs, and analysing the spread of forecasts that result. This approach is termed ensemble prediction (or ensemble forecasting) and allows more appropriate probability statements to be attached to each forecast. Ensemble prediction requires considerably more supercomputer capacity than single forecasts but provides a more realistic depiction of a forecast and its associated probability/uncertainty.

Response to the Terms of Reference

1. The efficacy of current climate modelling methods and techniques and long-term meteorological prediction systems

Summary: Seasonal forecasting for Australia is provided predominantly by the Bureau of Meteorology. Most operational forecasts are based on statistical forecast methods that have been used for over two decades. Some new, experimental dynamic forecasts show improved forecast skill and are expected to replace statistical forecasts in the near future.

The Bureau of Meteorology provides a number of long-range weather forecasting services along with its traditional short-term weather forecasting activities. Seasonal forecasting products and associated information services are delivered as part of the Bureau of Meteorology's Climate Monitoring Services Program, underpinned by the National Climate Centre, and R&D through the Centre for Climate and Weather Research (CAWCR). Forecast products are provided to a wide-range of users in Australia, including primary producers, water and natural resource management agencies, and emergency services agencies. These services also contribute to Australia's international scientific collaboration and obligations to the World Meteorological Organization and other international agencies. Seasonal forecasting research and development is also supported by a number of externally sponsored projects, whose aims are to provide increased capability and utility of extended range forecasts for specific applications desired by end users in industry, government or the community at large.

Both statistical and dynamic seasonal forecasting is used in Australia. Most operational seasonal forecasts currently delivered by the Bureau of Meteorology are based on statistical forecasting, developed and implemented since 1989 by the National Climate Centre (NCC). A similar statistical based regional seasonal forecasting scheme has been run since 1994 by the Queensland Government's Environmental Protection Agency. Both programs issue seasonal (three-month) rainfall outlooks using the format of the probability of exceeding the long-term seasonal median. Comparison of the NCC and Queensland Government systems indicates that the forecast skill of both systems is better than simply taking the average of conditions observed in the past. The NCC system generally performs better in the west and the Queensland Government system generally performs better in the centre and east of Australia.

Forecasts from dynamic forecasting systems are available through the Bureau of Meteorology but are still classed as 'experimental' because the modelling systems are still under development. Dynamic seasonal forecast products have been extended recently to give warnings of conditions potentially causing bleaching of coral in the Great Barrier Reef in the summer season ahead. These forecasts have been implemented as one of the tools that feed into the Great Barrier Reef Marine Park Authority's Great Barrier Reef Coral Bleaching Response Plan.

Analyses of dynamic seasonal forecasts to date indicate that they have greater skill (i.e. are more accurate in hindsight) than statistical forecasts but the uncertainty attached to some dynamic forecasts is suspected of being too low. That is, there is concern that the dynamic forecasts are 'over confident' and convey to users greater certainty than is warranted about future conditions. It is expected, however, that dynamic seasonal forecasts will soon produce regional products that can completely replace the existing statistical approach.

Projecting climate change decades and centuries into the future requires a global climate simulation capability that represents the land surface, the oceans, the atmosphere and the cryosphere and their interactions. The climate drivers such as greenhouse gas concentrations are specified. These models are sometimes referred to as Atmosphere-Ocean Global Climate Models (AOGCMs). CSIRO's AOGCM was used to deliver Australia's climate projections to the Intergovernmental Panel on Climate Change's Fourth Assessment in 2007. CSIRO has also developed capability for providing multi-decadal regional climate projections at much finer spatial scales than the AOGCMs.

While CSIRO's was among the cluster of better AOGCMs in the IPCC's Fourth Assessment, the state-of-the-art direction internationally is towards full climate and Earth system simulators that include key processes such as the global carbon cycle, dynamic vegetation growth and ecosystem changes, and the terrestrial water balance. A national approach is being taken to build this next generation climate and Earth system simulation capability in Australia through the development of ACCESS by CAWCR and the universities. Consistent with the international trend towards "seamless prediction", ACCESS will deliver short-term weather predictions, seasonal climate forecasts and multi-decadal climate projections.

2. Innovation in long-term meteorological forecasting methods and technology

Summary: Existing seasonal forecasts for Australia are based primarily on systems that have been in use for two decades and have reached the summit of their ability. Recent initiatives are focussed on developing next-generation dynamic seasonal prediction models that are expected to be responsive to changing climate conditions. The new world-class systems will require upgraded supercomputer infrastructure, enhanced observational inputs and state-of-the art data assimilation techniques to deliver cutting-edge operational services at improved spatial and temporal resolution.

Australia is building the next generation weather, climate and earth system simulation capability, called ACCESS (the Australian Community Climate and Earth System Simulator). ACCESS will deliver Australia's short-term weather forecasts, seasonal forecasts, and global and regional multi-decadal climate projections from local to global scales. ACCESS already is delivering short-term weather forecasts with greatly improved skill over the current system. The main needs for more rapid development and deployment of ACCESS are: significant enhancement of supercomputing infrastructure; increased staff capacity; and improved techniques for assimilating observations of the land, air and oceans, especially from satellites.

The direction in most weather forecasting groups internationally, as in Australia, is to replace existing empirically based statistical schemes with forecasting systems based on dynamic models when the latter have comparable or better skill than the existing statistical systems. The Bureau of Meteorology, in collaboration with CSIRO, has been developing successive versions of a dynamic coupled modelling system for seasonal forecasting, called POAMA: Predictive Ocean Atmosphere Model for Australia. The first version was implemented in Bureau operations in 2002 and generated forecasts of El Niño sea surface temperature indices. Evaluations of El Nino forecast skill, using retrospective forecasts, showed that POAMA was useful out to at least 9 months into the future. The POAMA system was upgraded in 2007 to include forecasts of the sea surface temperature in the equatorial Indian Ocean (also believed to be an important driver of weather and climate variability in Australia and the region).

Extensive analysis have been done of the capability of the POAMA system for regional forecasting of climate in the south east of Australia and in the subtropical Indian Ocean. These analyses have demonstrated that regional seasonal forecasts for Australia from POAMA have skill equivalent to, or better than, the current statistical approaches, though perhaps the uncertainty of the forecast is under-represented.

The Bureau of Meteorology and CSIRO, through their partnership in CAWCR, continue to develop and improve POAMA. The newest version, POAMA-2, is significantly more demanding computationally than its predecessors because of these improvements and so it will be used in real-time only on the Bureau's new supercomputer, which will be installed in late 2009. The new supercomputer will allow the skill for regional seasonal climate forecasts from POAMA-2 to be fully evaluated and delivered.

The next phase of POAMA development (POAMA-3) will be to include the seasonal forecasting system within ACCESS, which is being developed to provide Australia's next generation weather prediction system and climate simulation system (see Appendix 1). ACCESS is already delivering much-improved short-term weather forecasts compared to the current operational system and is expected to deliver significant improvements in seasonal forecasts. Both the short-term weather forecasts and longer-term seasonal forecasts from ACCESS will be enhanced significantly by improved assimilation of data from various land, ocean, automated and satellite sources of observations. Delivering the full benefit of the ACCESS-based system through real-time operation of POAMA-3 will require a further step-change in supercomputing resources available to run the system in ensemble prediction mode at improved spatial and temporal resolution.

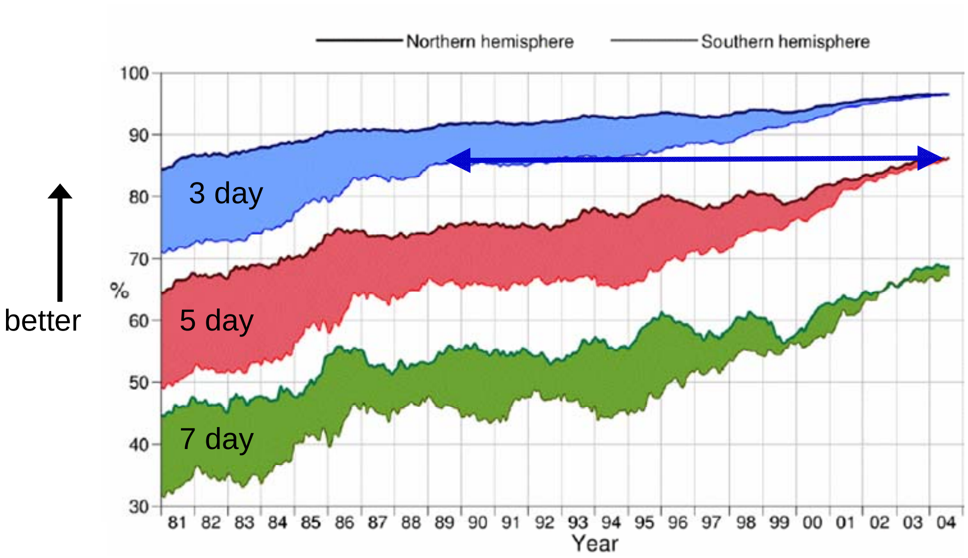
The ACCESS project has harnessed Australian meteorological modelling expertise to focus on developing a unified, national weather and climate modelling system, but many more issues need to be addressed than available resources allow. This makes progress slow. Some of the key areas of research and development most likely to improve seasonal forecasting skill in all model systems include:

- Improving the simulation of El Niño and its different modes;
- Improving the simulation of the Indian Ocean variability;
- Improving the simulation of weather phenomena (e.g. cut off lows, blocking, tropical cyclones, tropical intra-seasonal waves, etc) and tropical processes that contribute to phenomena such as El Niño, which are all significant drivers of Australia's regional climate; and
- Improving data assimilation techniques that incorporate in situ and satellite observations into the ACCESS model.

Hence, the two key infrastructure assets required to deliver significant improvements to next generation seasonal forecasts will be improved assimilation of diverse observation streams and further upgraded supercomputing capacity. Increased scientific capacity will be required to achieve more rapid progress in key areas.

Weather forecasts have improved significantly over the last few decades as they have evolved from empirically based forecasts to today's forecasts which are based on computer models of the atmosphere. The new dynamical seasonal climate forecasts employ the same approaches to atmospheric modelling as in weather forecasts but they are more complex because they are coupled to models of the ocean. The figure below shows the improvement in skill in weather forecasting over the last few decades and this gives scientists confidence that significant improvements in seasonal forecasts can also be achieved[1]. Much of the improved skill seen in the figure below arises not only from better model representation of the atmosphere and oceans, but also the assimilation of increasing amounts of satellite data.

European weather model skill improvement



Skill of the 5 day forecast today is as good as the 3 day forecast in 1989 (southern hemisphere)

Courtesy of ECMWF

[1] Hollingsworth, A., P. Viterbo, and A. J. Simmons, 2002: The relevance of numerical weather prediction for forecasting natural hazards and for monitoring the global environment. ECMWF Tech. Memo. 361, European Centre for Medium-Range Weather Forecasts, Shinfield Park, Reading, United Kingdom, 29 pp. [Available online at www.ecmwf.int/publications/library/ecpublications/_pdf/tm361.pdf.]

3. The impact of accurate measurement of inter-seasonal climate variability on decision-making processes for agricultural production and other sectors such as tourism

Summary: Reliable seasonal forecasting has considerable potential to deliver tangible benefits for forward planning and business operations in agriculture and water resources, and other industry and government sectors and the broader community. Some benefit already exists but would be enhanced through improved seasonal forecasting, clarification and education about how to interpret and apply forecasts appropriately, and therefore, increased user-confidence about what season forecasts do (and don't) offer.

The term "accurate measurement" in the Term of Reference is interpreted to mean "accurate forecasting" and the following comments reflect the 'forecasting' focus of this Inquiry.

Australia has one of the most variable climates of any country, exhibiting considerable variations in rainfall, temperature, winds, cyclones and other weather phenomena from season to season, from year to year and from decade to decade. Seasonal, yearly and decadal variations in climate pose challenges to all industries that are affected to any degree by the weather.

Sound weather forecasts, including seasonal forecasts, are central to good climate risk management and enabled informed planning and decision making well in advance of key activities. Seasonal forecasts can be used to maximize benefit in good years as well as avoid losses in bad years. For example, 70-80% of profits are made in 30% of years in Australia's southern wheat-growing regions. Improved information about which years are likely to be better (or poorer) thus has considerable potential benefit.

A seasonal climate forecast can be used to alter the time of sowing, the area sown and the amount of fertilizer applied. Different industries, different regions and different management options require forecasts for different times of year and with different lead times. There are, of course, other considerations that influence management decisions but seasonal forecasts provide a unique part of an overall forward planning and risk management strategy and help determine which way to "lean", not which way to jump. This is important because of the uncertainty inherent in such forecasts.

There is a wide range of industries that can and do benefit from seasonal forecasts, and a wide range of management decisions that can be altered in response to seasonal forecasts. Examples of potential or realized relevance of seasonal forecasts include:

- Dryland cropping, influencing sowing date, area, variety, fertilizer application, and mixed farming choices;
- Irrigated cropping, affecting use of irrigation water;
- Grazing, modifying stocking rates;
- Horticulture, influencing variety selection of annual crops, expected harvesting schedule and market supply;
- Viticulture, affecting planning for irrigation and harvests;
- Large infrastructure projects, allowing planning for rain delays;
- Emergency services, assisting planning and preparedness for likely extreme events;
- Water resources, influencing water rationing and irrigation allocations; and
- Tourism, through planning capacity and services for warmer/cooler seasons.

The limits to skill and uncertainty of seasonal forecasts are not yet well understood by end users, however, and users' expectations of potential improvements in forecasts may be higher than can be achieved. Seasonal forecasts will be most valuable and informative if their uncertainty is well-known, well-communicated and well-used in decision making. Education of end-users in the best use of forecast probabilities is essential and end-user participation in forecasting research and development provides considerable benefit.

Climate forecasts have been estimated to deliver a net benefit to agricultural production in Australia of 3-10%. The current skill of forecasts in most regions, however, is relatively low and there is fairly widespread lack of confidence in seasonal forecasts and uncertainty about how, or whether, to use them in agricultural decisions. Consequently, other studies have indicated that the realised benefits of seasonal climate forecasts have been more modest. Various Research and Development (R&D) funding agencies have estimated the value of return on R&D investment in seasonal forecasting to be in the range 1.7-4.7 to 1.

Seasonal forecasts can be used to obtain natural resource and risk management benefits in addition to economic benefits. Some work has focused on the use of seasonal forecasts to alter plant rotation strategies to reduce groundwater build-up and associated salinity increases, though the benefit so far from such studies has been small. Other work in the grazing industry has shown how substantial increases in farm income can be achieved by adjusting stocking rates to match forecasts of plant growth and avoiding increases in natural resource degradation in seasons expected to have lower plant growth. This is a clear benefit of seasonal forecasting but is difficult to quantify economically.

Benefits from seasonal forecasts also are likely to apply more broadly than at the individual farm level. There is considerable potential for whole-of-industry benefit from seasonal climate forecasts. For example, sugar millers in Queensland use seasonal climate forecasts to plan mill maintenance and operating schedules. Transport and storage enterprises likewise could benefit from advance planning of capital expenditure, maintenance and operations based on robust seasonal forecasts.

The water resources management sector also relies heavily on seasonal forecasts and longer-term climate projections. A seasonal water availability prediction service has been needed in Australia for many years, especially in recent periods of drought. Reliable seasonal predictions of water availability are highly valuable for water resources management and irrigated agriculture and will provide useful information on water allocation forecasts, water markets, and irrigation water availability. The Water Information Research and Development Alliance (WIRADA) between the Bureau of Meteorology and CSIRO, in concert with CAWCR are undertaking R&D to develop modelling systems that will deliver a seasonal water availability prediction service based on improved seasonal weather forecasts. A statistical prediction system is being developed and has been shown to provide useful seasonal streamflow predictions. A dynamic approach to seasonal streamflow prediction is also being developed. Implementation of such a system will require considerable supercomputing resources and data assimilation capacity.

Air quality remains an issue of importance to the health and wellbeing of Australians, with some of the focus now shifting to including air quality in national climate adaption strategies. Long-term air quality forecasting also depends on sound seasonal weather prediction. Early warning of likely air quality issues provides information for policy makers in formulating effective and targeted long-term air pollution policies that, increasingly, need to be harmonized with strategies for mitigating and adapting to climate change. Long-term air quality forecasting depends on accurate long-term meteorological forecasting because the meteorology affects air quality both directly and indirectly. Potential benefits from seasonal air quality forecasting include:

- More effective and better targeted air pollution control strategies;
- Improved seasonal forecasts of hospital admissions because of air-quality-related patterns in asthma and other respiratory ailments; and
- Quantifying the links between air quality and climate to assist mitigation and adaptation strategies.

Key challenges to enhance the utility of seasonal forecasts for users include not only improving the skill, timeliness and delivery of the forecasts but also improving communication and understanding for users about the appropriate interpretation and use of the valuable but uncertain information seasonal forecasts contain.

4. Potential benefits and applications for emergency response to natural disasters, such as bushfire, flood, cyclone, hail, and tsunami, in Australia and in neighbouring countries

Summary: Emergency response management by definition involves reacting to largely unpredictable events. Seasonal forecasting cannot provide prescriptive forecasts of specific events but can improve significantly the expectation of what sort of events (e.g., fire or flood) are most likely for coming seasons. These forecasts allow strategic planning of response logistics and focus and provide advance warning for emergency response groups, industry, and the community about what might be expected for future seasons.

Emergency management practice has moved from being simply about planning efficient responses to the impact of episodic extreme natural hazard events to a greater focus on defining and understanding the risk of such events and preparing for, planning and mitigating this risk. The trend more recently has shifted to include building community and infrastructure resilience to disasters in an all-hazards context. Longer term and inter-seasonal meteorological forecasting underpins this approach.

The main benefit of long-term meteorological forecasting to emergency management and disaster mitigation lies in the ability to predict what types of events are more likely to occur in the medium to long-term. Knowledge of the likelihood of various types of extreme events in the coming season allows disaster mitigation preparation to better focus on the more likely threats. This would include biasing the emphasis of logistics planning and pre-season public education towards the most likely hazards expected in the coming season.

The Bureau of Meteorology has close relationships with the emergency management and emergency services sectors across all jurisdictional levels and provides support all emergency management planning processes and emergency services responses. The availability of improved seasonal forecasting will assist the Bureau in the provision of this support.

Prediction of meteorological conditions (for example, droughts, prolonged heavy rain, the occurrence of tropical cyclones, bushfire risk) a few weeks to months in advance can provide considerable socio-economic benefit both within Australia and to most Pacific Islands and Territories and to Asian countries to the north of Australia in planning to combat potential natural disasters. Extreme weather and climate have had a very high impact especially on island nations (including on their GDP), where often the impacts of natural disasters are nation-wide. These countries have benefited from scientific advancements and related technological developments in Australia in weather and climate monitoring and seasonal forecasting.

Tropical cyclones are the most destructive weather phenomena that impact on northern Australia and adjacent areas of the South Pacific and South Indian Oceans. The inter-annual variability in tropical cyclone numbers is large and is linked to variations in sea surface temperatures and broad scale climate patterns such as the El Niño-Southern Oscillation (ENSO). Tropical Cyclone pre-season briefings and awareness campaigns are delivered annually to a range of government, community and emergency management stakeholders across tropical Australia. Reliable and robust medium and long-term meteorological information is invaluable to emergency and community managers in their planning for the coming season. This is particularly so in remote and indigenous communities that are likely to be isolated by flooding for relatively long periods. There are particular demands for seasonal outlook services (or risk assessments) from the resource rich areas of Western Australia and the Northern Territory, as well as emergency managers. Provision of improved services will depend on improvement in dynamic seasonal forecast capability and skill.

The provision of early seasonal forecast information assists fire and land management agencies with pre-season strategic planning. Such planning is intended to enhance community safety through improved effectiveness of pre-season fire hazard reduction and improved deployment of fire fighting resources such as aerial fire-fighting equipment. Fire weather forecasts are an essential component of all aspects of fire risk assessment at a range of time scales:

- In the short-term (hours to a week) for incident management;
- Seasonally, for wildfire response planning (e.g., staff recruitment, training and regional deployment, procurement and deployment of plant); and
- Over annual and longer periods for assessing fire risk to populations, property and the environment in a changing climate. Current scenarios predict an increasing trend in fire danger in SE and SW Australia.

There is increasing pressure to mitigate the risk of wildfire by extensive prescribed burning programs. The window of opportunity within which prescribed burning may be completed safely however, appears to be narrowing. A challenge is to develop the accurate forecasting tools that on the one hand minimise the number of lost opportunities for prescribed burning in this diminishing window, and on the other avoid prescribed burning events in times when current prescription rules fail to account for unusual weather events.

There is substantial evidence that bushfire season duration and severity is potentially predictable using links to seasonal climate variability such as ENSO. Advance warning of severe or benign fire seasons is a very real possibility, which also provides potential to manage fuels and preparedness outside of the fire season.

Emergency managers, local government, and residents would benefit also from forecasts of likely changes to frequency of riverine and storm surge flooding on monthly and seasonal timescales. Techniques to diagnose these extreme events based on ensembles of seasonal forecasts will provide seasonal probabilities of increased or decreased likelihood of floods.

5. Strategies, systems and research overseas that could contribute to Australia's innovation in this area

Summary: Australia has great dependence on international observation systems such as satellite data and benefits considerably from weather and climate forecasting technology developments in other countries. Australia's next generation forecasting systems are being built from model components mostly developed in the USA, UK or Europe, but enhanced for Australian conditions. National capacity to further develop forecasting technologies is essential, because of Australia's specific vulnerability to Southern Hemisphere phenomena that are not the focus of most developed nations' forecasting activities. Continued benefit from international sources substantially rests on continued Australian contributions to global research and development activities.

The science of predicting the weather is global. Australia's weather forecasts are extremely dependent on data obtained from satellites owned by other countries, especially Japan, US, Europe, China and Taiwan, especially for forecasts beyond 12 hours. These data are freely supplied to Australia and include not only land surface and air observations but also ocean observations such as sea surface temperature, ocean colour, surface winds and surface sea level (non coastal).

The predictive skill for southern hemisphere meteorology is now similar to that for the northern hemisphere – a direct result of the successful use of internationally available satellite data and contributions from Australian research and development. Smarter systems and better use of existing and expected data streams, however, are needed to realise the full potential of weather forecasting systems and to provide forecasts at smaller spatial scales with reliability over longer lead times. Australia will need to engage with the international research and operational forecasting communities where new technologies are being developed to improve short and long-term forecasting skill. International engagement by the Australian science community is needed to ensure that Australia has early access to new technologies that we do not have capacity to develop locally.

Maintaining agreements for data provision with international agencies such as the World Meteorological Organisation (WMO) as well as individual countries is essential for Australia, along with engagement in international programs to develop and use applications for these observations. Such engagements include leading Australian ground-truth calibration and validation studies and participation in international science teams.

Climate is a global issue, and international agreements are crucial for global progress, including operational monitoring and baseline measurements of atmospheric levels of greenhouse gases. Other international programs include: various WMO groups for the science, forecasting and mitigation of tropical cyclones, monsoons, air quality; the World Weather Research Program for forecast system improvements (e.g., Sydney, Beijing and the upcoming Winter Olympics are all catalysts for programs that involve multiple countries improving forecast systems); and international programs such as the Global Energy and Water Cycle Experiment) that aim to improve predictive capability for hydrological events.

In situ data streams are a necessary part of the science of meteorological prediction, and many of the observing networks in Australia are part of a wider global network. This means that Australia benefits from the global data streams by virtue of running an Australian regional component of coordinated global activities. Examples include:

- Argo ocean profiling sensors - Australia currently only contributes 50% coverage of the region around us (90E-180E, ice - equator). International partners cover the other 50% and the rest of the planet;
- TAO/TRITON tropical moored ocean sensing array - Data from this extensive array are key for pacific and ENSO/Indian Ocean Diapole forecasting systems (Australia makes no contribution but has access to the data by virtue of other collaborations);
- Global Atmospheric Watch - Australia provides essential baseline greenhouse gas concentrations measurements at the Cape Grim Baseline station, as part of this global network;

- Fluxnet - An international program of micro-meteorological measurements of land – air exchanges of energy, water and carbon that provides important calibration data for weather and climate models;
- The Bureau of Meteorology, through the POAMA system, is a WMO global seasonal prediction centre, required to provide seasonal forecasts to WMO regional climate centres; and
- The World Climate Research Program supports several international efforts to exchange and compare forecasts from different global modelling centres, providing invaluable input for improvement of forecast systems.

The development of Australia's next generation weather and seasonal forecasting system, climate model and earth system simulation capability, all based on ACCESS (Appendix 1) is built on international research and development. The Bureau of Meteorology and CSIRO, through CAWCR, is developing ACCESS from model components from Australia, the United Kingdom and the United States of America. The strategy in ACCESS is to build a coupled model mainly using the latest state of the art components from overseas but with enhancements by Australian scientists specific for Australian weather and climate. Development of ACCESS entirely within Australia would have been prohibitive but, equally, simple adoption of 'off the shelf' model technologies from elsewhere for application in Australia would be inadequate and would leave Australia exposed to over-dependence on decisions made elsewhere about forecasting model development.

Robust weather and climate prediction requires the use of the latest global observations from the ocean, land surface, cryosphere and atmosphere. National efforts usually focus on improvements that are specific to local national weather and climate variability but build on systems and knowledge developed internationally. The challenge of improving coupled dynamic models used for seasonal forecasting prediction is now an internationally shared activity, with improvements in components shared or imported from one organization to others. The currency for participation in this valuable research and development exchange is participative collaboration, requiring a robust national capability.

Conclusions

Short-term weather forecasting has improved significantly over recent years, as has our ability to model the Earth system to produce better projections of future climate and climate change. Seasonal forecasts have been developed over the last two-three decades based mainly on statistical forecasting methods that have now reached the summit of their skill. Dynamic seasonal forecasting technologies based on the same modelling that has improved short-term weather forecasts and very long-term climate projections are now recognised as the next generation of seasonal forecasting methods. Australia's Southern Hemisphere location demands locally tuned and managed versions of such technologies. Development of these tools will provide significant advances in seasonal forecasting skill and resolution but will require significant further investment in supercomputing infrastructure, observation acquisition and assimilation and scientific expertise.

Appendix 1: The Australian Community Climate and Earth System Simulator

ACCESS – a world competitive, weather and climate simulation capability for Australia

Subject
An overview of the Australian Community Climate and Earth System Simulator (ACCESS) initiative, which is being undertaken in the Centre for Australian Weather and Climate Research (CAWCR)[2], in collaboration with Australian universities, to build a new, world class weather and climate simulation capability in Australia.

Background
Australia is particularly vulnerable to the risks of climate change and year-to-year climate variability. Climate extremes such as heatwaves, tropical cyclones and bushfires are hazards with which Australians already live. Climate change will result in even greater challenges with declining rainfall and increased frequency of drier and warmer droughts, at least for the southern part of the continent, and the risk of more intense and frequent extreme events such as heavy rainfall and tropical cyclones in the north. Mitigating and adapting to climate change is therefore a priority national challenge.

A national capability in climate and earth system simulations and observations, that is internationally competitive and world class, is essential to equip Australia to meet this challenge. Having an Australian capability focussed from the perspective of the Southern Hemisphere also will provide internationally unique contributions to global efforts to respond to climate change.

What is ACCESS?
ACCESS is under development to be Australia's "next generation" weather and climate simulation system. ACCESS will produce the nation's weather forecasts by late 2009 and by 2011 it will provide long-term global and regional climate projections and be a key platform for Australia's contributions to the IPCC Fifth Assessment.

The Australian Bureau of Meteorology and CSIRO have joined forces to form the Centre for Australian Weather and Climate Research (CAWCR) to progress, *inter alia*, the development of ACCESS and ensure that ACCESS is internationally-competitive. The Bureau and CSIRO also have negotiated a Collaboration Agreement with the U.K. Meteorological Office's (UKMO) Hadley Centre to adopt the UKMO Unified Model, atmospheric chemistry module and data assimilation scheme as the core of ACCESS. This heralds a significant strategic alliance between Australia and the UK to collaborate on the development and deployment of a consistent approach to climate and earth system modelling.

Australian researchers will focus on key aspects of identifying, understanding and modelling climate and weather drivers in the Southern Hemisphere, such as the prediction of ENSO, the Indian Ocean Dipole and simulation of the Southern Ocean, to feed into ACCESS and the UKMO models. Australian researchers are building a new land surface scheme (CSIRO Atmosphere – Biosphere Land Exchange model, CABLE) to ensure that Australian vegetation is well represented in the global model and an advanced global ocean and sea ice model (Australian Community Ocean Model, AusCOM) to capture the major features of Southern Hemisphere ocean circulation and their effects on climate.

The alliance between CAWCR and the University sector will build critical mass in climate and earth system simulation, research and training in Australia. International collaborations with the UK, NZ, Korea and other nations will significantly build capacity across the region.

What will ACCESS deliver?
ACCESS will provide Australia with a world-competitive coupled climate and Earth system simulation capability by fulfilling the vision for a "seamless prediction" system for Australia

ACCESS will provide a unified simulation platform for all time scales from numerical weather prediction to seasonal prediction and longer-term climate projections that can be applied at global, regional and local spatial scales. Seamless prediction is acknowledged by the global research

[2] The Centre for Australian Weather and Climate Research is a jointly managed research partnership between the Bureau of Meteorology and CSIRO.

community to be the state-of-the-art approach needed to deliver high quality weather and climate simulations.

ACCESS also will provide advanced capability to enable environmental prediction such as for air quality and renewable energy (wind, wave and solar) resources, as illustrated in the following figure.