Australian Government
Bureau of Meteorology

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Submission No: 4

In reply please quote
30/3200

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

Dear Sir,

I refer to your 24 March 2009 invitation to the Acting Director of Meteorology, Dr Neville Smith, for the Bureau to tender a submission to the Inquiry into Long-Term Meteorological Forecasting in Australia being conducted by the House of Representatives Standing Committee on Industry, Science and Innovation.

I am pleased on behalf of Dr Smith to enclose the Bureau's submission. You will note that the submission has been authored in part by scientists from the Joint Bureau of Meteorology/CSIRO *Centre for Atmospheric Weather and Climate Research*. Should CSIRO also make a submission, there is likely to be some commonality with the Bureau's submission, especially with respect to the underlying science and the current technological approaches being explored in Australia and elsewhere to improve forecasting on seasonal to interannual timescales – an inevitable by-product of the collaboration.

Nonetheless, given the distinctive missions of the two organisations, we anticipate that the differences between the submissions will be sufficient to warrant them being viewed by the Committee as mostly complementary rather than duplicative.

Yours sincerely,

Michael J. Coughlan
A/Chief Climatologist

23 April 2009.

Submission by the Bureau of Meteorology to the

Inquiry into long-term meteorological forecasting in Australia

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

23 April 2009

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Executive Summary

Meteorological forecasting and climate modelling are important to Australia's economic, environmental and social well-being and prosperity. Australia's location and size expose it to a range of weather extremes such as heatwaves, bushfires, cyclones, floods and storms. Predictions of weather and climate at time scales from hours to days and across seasons can influence decisions that range from emergency management procedures and systems through to when or whether to plant particular crops.

Australia is also particularly vulnerable to the impacts of climate change which is projected to result in decreased rainfall and increased frequency of drier and warmer droughts for the southern part of the continent, with more intense and frequent extreme events such as heavy rainfall and tropical cyclones in the north. Indeed this pattern of a general drying across southern Australia and an increase in rainfall across the north is now evident in the climate record of the past 10-20 years.

Current Bureau of Meteorology policy is to maintain a seasonal climate outlook service that draws on meteorological and related observations, a climate modelling capability, a suite of forecasting tools, and information available from similar services and research elsewhere.

Key Points

Long-term meteorological forecasting (hereafter referred to as 'season' or 'seasonal' forecasting) is interpreted in this submission to comprise primarily forecasting from one to several months in advance. The term "operational" is used to qualify routine and regular products and services for which there is full documentation of the scientific basis and verification.

The Bureau of Meteorology has interests in forecasting meteorological and related conditions on all timescales. The Bureau currently has a strong and reliable weather forecasting capability out to around seven days and some capability at seasonal timescales to produce outlooks for general rainfall and temperature conditions likely over a coming three-month period. Research is underway in collaboration with CSIRO to improve this latter capability and also to develop more robust projections of climate change at time scales out to several decades or more. There is also a research effort underway to improve forecasting on the intra-seasonal (2-8 week) time-frame, particularly in tropical Australia. This submission, however, is focused on seasonal forecasts.

The key points of this submission against the five terms of reference are summarised as follows:

(1) Seasonal forecasting for Australia is provided predominantly by the Bureau of Meteorology's Climate Services Program. Most operational forecast products are based on statistical forecast methods that have been used for more than two decades. Some new, experimental dynamic forecasts are showing improved forecast skill and are expected to replace statistical forecasts in the future. They are currently used to provide additional guidance for the operational service.

(2) The existing operational seasonal forecasts for Australia appear to have reached their peak level of performance and may even be declining in skill as the climate changes. Recent initiatives are focused therefore on developing next-generation dynamic seasonal prediction models that can take account of changing climate conditions.

(3) Reliable seasonal forecasting has considerable potential to deliver tangible benefits for forward planning and business operations in agriculture and other industry and

government sectors. The benefits already being captured would be enhanced through improved seasonal forecasting, clarification and education on the appropriate interpretation and application of forecasts and, accordingly, increased user-confidence about what season forecasts do (and don't) offer.

(4) Emergency response management by definition involves reacting to extreme events. Seasonal forecasting cannot provide prescriptive forecasts of specific events but can improve significantly our knowledge of the likely occurrence during coming seasons of meteorological conditions conducive to extreme events such as fire or flood. Such forecasts facilitate strategic planning and response logistics and provide advanced warning for emergency agencies, industry, and the community.

(5) Australia's seasonal forecasts depend greatly on international observation systems, such as satellites, and benefit considerably from weather and climate forecasting technology developments in other countries. Australia's next generation forecasting systems are being built from model components originally developed in the USA and Europe. National capacity to adapt and further develop forecasting technologies is essential owing to Australia's vulnerability to climate variations specific to our region and the need to focus on the forecasting of Southern Hemisphere phenomena which may not be the highest priority for northern hemisphere nations.

The Bureau of Meteorology's expertise in relation to the Inquiry's Terms of Reference

Under the Meteorology Act (1955) the Bureau of Meteorology has responsibility for the collection of meteorological and related data and the forecasting of weather and the state of the atmosphere, including the issuing of warnings for severe events likely to endanger life and property. The Act also requires the Bureau to produce records of weather observations and maintain the national climate record. For the past two decades the Bureau has been issuing forecasts on expected anomalies in rainfall and temperature across Australia over the coming three months, i.e. seasonal forecasts. This function was explicitly recognised through the Government's endorsement of the Recommendations of the 1996 Slatyer Review of the Operation of the Bureau of Meteorology.

High quality observations of Australia's climate underpin all related climate research, understanding and forecasting. Records have been collected for more than 100 years at many sites across Australia and the Bureau of Meteorology takes great care with and adopts a responsible approach to the quality control and management of these data for the climate record. The Bureau of Meteorology provides many products and services that are a direct result of analyses based on Australia's climate record.

These observations and those shared by other agencies and institutions around the globe, predominantly under the auspices of the World Meteorological Organization, underpin weather and seasonal forecasting capabilities in Australia and throughout the world. An accurate description of the present state of the climate system is essential for determining its likely future evolution.

The Bureau of Meteorology has been using global scale models of the atmosphere for numerical weather prediction for in excess of three decades. These same models, enhanced with the capability to model land surface and ocean properties, form the basis for the future evolution of systems to be used in generating seasonal forecasts. A great deal of research and development has gone into improving the understanding of the climate system and how to simulate its evolution with these models. The Bureau of Meteorology, through its collaboration with CSIRO in the Centre for Australian Weather and Climate Research (CAWCR), now has world-class capability in this key area of climate and atmospheric research.

CAWCR, in collaboration with several universities, is building the next generation weather and climate model, called the Australian Community Climate and Earth Simulator (ACCESS). ACCESS will provide Australia with a common simulation platform for delivering weather forecasts as well as seasonal climate predictions and longer-term, multi-decadal climate projections.

This submission provides an introductory preamble about meteorological forecasting with particular emphasis on seasonal to interannual timescales and addresses each of the Terms of Reference, commenting briefly on the state of the science, outlining the current seasonal forecasting services provided by the Bureau of Meteorology and the steps being taken to improve those services.

Introduction

Preamble about meteorological forecasting

Long-term meteorological forecasting (hereafter referred to as 'season' or 'seasonal' forecasting) is interpreted in this submission to comprise primarily forecasting climate outcomes from one to several months in advance and much of what is said below applies to this sub-category. No comment is made in this submission on short term weather forecasting (hours to a several days), on `intra-seasonal' (2-8 week) forecasts currently being trialled over tropical Australia, or on longer term climate-scale projections (years to centuries) other than as necessary for context.

Meteorological forecasting in general involves gathering observations about past or present conditions that define and influence weather, and using those observations in some way to predict what the meteorological conditions[1] will be at some future time. Forecasts can be based on statistics of the past ('statistical forecasts') but for weather are now almost exclusively based on complex models of the atmosphere, earth surface and ocean that take as input the observations of existing and past conditions. The digestion of observations into the models (termed data assimilation) allows the models to be set up with credible starting conditions from which to simulate the evolution of weather systems into the future ('dynamic forecasting'). Both approaches are now also available for seasonal forecasting.

A key assumption of statistical forecasting is that past weather and climate patterns are sound indicators of what can be expected in the future. Climate change challenges this assumption because it suggests that in the future the conditions that affect weather and climate increasingly will exceed the bounds of past experience. Consequently, a climatic state, i.e. the average conditions over a period such as a month or season, which is outside the bounds of the climatic record used to construct a statistically based forecast system, will likely be less well forecast than any climatic state that is within the bounds of that record. Dynamic forecasting, however, is based on fundamental physical and dynamical relationships; relationships that are largely invariant to climate and climate change, and are conditioned by assimilating (dynamically) observations of the past and present state. Hence, dynamic seasonal forecasting has distinct advantages over statistical forecasting in a changing climate regime.

Dynamical forecasting models use extensive mathematical calculations based on the laws of physics, but do not start from perfect representations of the weather system (either in terms of equations or observations) and so do not produce exact forecasts of the future. Indeed, even the smallest of errors in an otherwise perfect model will grow over time, limiting predictability of weather to around 10-14 days. 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 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 more skilful than forecasts of the weather five days from now. The skill of predictions of climate (e.g., average weather for a month rather than on a particular day) retain 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

[1] The term 'weather' refers to the meteorological conditions that can be observed or recorded at a given point in time. Meteorological conditions or 'weather' when average over a period of typically a month or more are now generally referred to as the current climate state, which will vary from month to month, year to year etc. 'The climate' of a locality usually refers to conditions throughout an annual cycle averaged over a period of around 30 years. However, with the growth in time of the historical climate record coupled with the study of paleoclimatic records, it has become clear that climate varies naturally on all time and space scales.

conditions on particular days in a future season. The expression 'short term climate forecasts' is sometimes used as another alternative to seasonal or long-range forecasts.

Uncertainty, which grows with the length of a meteorological forecast, is being quantified by generating a series of forecasts under slightly different starting conditions in the model, which reflect the level of uncertainty in not being able to exactly prescribe the current state of weather everywhere, and then analysing the spread in the series of forecasts. This approach, termed ensemble forecasting, allows more appropriate probability statements, i.e. estimates of uncertainty, to be made about a forecast. Ensemble predictions generally provide more robust and reliable assessments of forecast conditions.

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's Climate Services Program. Most operational forecast products are based on statistical forecast methods that have been used for more than two decades. Some new, experimental dynamic forecasts are showing improved forecast skill and are expected to replace statistical forecasts in the future. They are currently used to provide additional guidance for the operational service.

The Bureau of Meteorology (the Bureau) provides a number of long-range forecasting services along with its weather forecasting activities. Seasonal forecasting products and associated information services are delivered by the Bureau's Climate Services Program, chiefly through its National Climate Centre (NCC). These forecasts are provided to a wide range of users in Australia, including primary producers, water and natural resource management agencies, and emergency services agencies.

Regional climate variations on timescales of seasons are predictable to an extent, largely because of the influence of the oceans surrounding Australia and in particular the tropical Pacific Ocean to the north and east. The upper layers of the ocean interact with the atmosphere, thereby affecting weather patterns. The time-scales of predictable upper ocean variability are relatively long compared with the atmosphere, of the order of months to perhaps one year, and hence there is a long-term "memory" in the oceans that can influence the atmosphere on monthly to seasonal time scales. With knowledge of the present state of the oceans, there is potential to forecast the regional climate in to the future.

Both statistical and dynamic seasonal forecasting methods are used in Australia. Most operational seasonal forecasts currently delivered by the Bureau are based on statistical forecasting, developed and implemented since 1989 by the NCC. A similar, statistically based regional seasonal forecasting scheme has been run since 1994 by the Queensland Government's Environmental Protection Agency and other predecessor agencies. 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 systems indicates that both systems show widespread forecast skill better than simply taking the average of conditions observed at that time of the year in the past. The NCC system generally performs better in the west and the Queensland system generally performs better in the centre and east of Australia. Both groups also issue similar type forecasts for maximum and minimum temperatures.

Forecasts from dynamic forecasting systems are available through the Bureau but are still classed as 'experimental' because some key products generated by the modelling systems are assessed as insufficiently reliable to replace similar products generated using the statistically based forecast system.

Analyses of the experimental dynamic seasonal forecasts to date indicate that they have greater skill (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 about future conditions than is warranted. There is optimism, however, that dynamic seasonal forecasts will soon produce regional products with sufficient reliability to completely replace the existing statistical approach.

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

Summary: The existing operational seasonal forecasts for Australia appear to have reached their peak level of performance and may even be declining in skill as the climate changes. Recent initiatives are focused therefore on developing next-generation dynamic seasonal prediction models that can take account of changing climate conditions.

The direction being taken by most weather forecasting groups internationally, as in Australia, is to replace existing empirically based statistical schemes with systems based on dynamic models, when the dynamic systems have comparable or better skill than the existing statistical systems. The Bureau, 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 related sea surface temperature variations. Skill for El Niño related forecasts has been evaluated from retrospective forecasts and is useful out to at least 9 months into the future. The POAMA system was upgraded in 2007 and its products were extended to include experimental forecasts of the sea surface temperature in the equatorial Indian Ocean, also believed to be an important driver of climate variability over Australia.

Extensive analysis of the capability of the POAMA system for regional forecasting of climate in the south east of Australia and in the subtropical Indian Ocean has been undertaken in conjunction with external partners. These programs have demonstrated that regional seasonal forecasts for Australia from POAMA have skill equivalent to or better than the current statistical approaches, though again with under-represented uncertainty.

The Bureau and CSIRO, through their partnership in the Centre for Australian Weather and Climate Research (CAWCR), are continuing to develop POAMA. A new version, POAMA-2, has been developed that incorporates improvements to components that represent different parts of the climate system. POAMA-2 will be used to generate experimental forecasts when the Bureau's new supercomputer is installed in late 2009. The new supercomputer will provide the required capacity to evaluate the skill of POAMA-2 from how well it would have performed in generating past seasonal forecasts – so called hindcast evaluation. If the hindcasts when evaluated against actual outcomes are shown to be sufficiently accurate and reliable, then POAMA-2 forecasts will be integrated into the suite of tools used to generate the operational seasonal forecast products issued by the Bureau of Meteorology.

The focus of the next phase of development (POAMA-3) will be to include the seasonal forecasting system within the Australian Community Climate and Earth System Simulator (ACCESS) that is being developed to provide Australia's next generation weather prediction system and the next generation climate change simulation system. ACCESS is already delivering much-improved short-term weather forecasts compared with the current operational system and is expected to deliver significantly improved capability in generating seasonal forecasts. Both aspects of ACCESS will be enhanced significantly by improved and more diverse data assimilation from various land, ocean, automated and satellite sources of observations.

The ACCESS project has harnessed the local expertise to focus on one national weather and climate modelling system. Some of the key areas of research and development most likely to improve seasonal forecasting skill in all model systems include:

- Improvement of the simulation of El Niño and its different manifestations;
- Improvement of the simulation of the Indian Ocean variability;
- Improvements of the simulation of local weather phenomena (e.g. cut off lows, blocking, tropical cyclones, tropical intra-seasonal waves, etc);
- Improvements of the simulation of the tropical processes whereby phenomena such as El Niño impact local climate systems; and
- Improvements to techniques that incorporate in situ and satellite data into the ACCESS model.

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 other industry and government sectors. The benefits already being captured would be enhanced through improved seasonal forecasting, clarification and education on the appropriate interpretation and application of forecasts and, accordingly, increased user-confidence about what season forecasts do (and don't) offer.

The term "accurate measurement" in this 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 meteorological forecasts, including seasonal forecasts, are central to good risk management in agriculture and other weather sensitive industries as they enable informed planning and decision making well in advance of undertaking key activities. Skilful seasonal forecasts can be used to maximise 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 southern wheat-growing regions. Improved information about which years are likely to be better (or poorer) has considerable potential benefit. A seasonal climate forecast can be used to determine the optimum time to sow, the area sown and the amount of fertilizer that might be required. Different industries, different regions and different management options require forecasts with different lead times and at different times of year. There are, of course, other considerations in determining the best management decisions; using seasonal forecasts is just one part of an overall forward planning and risk management strategy, which helps determine the way to lean, and not necessarily the way to jump. This distinction is important because of the uncertainty inherent in seasonal 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 realised relevance of seasonal forecasts include:

- Dryland cropping, influencing sowing date, area, variety, fertilizer application, and mixed farming choices;
- Water resources, influencing reservoir management; water rationing and irrigation allocations;
- 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 irrigation planning, pruning and harvest planning;
- Large infrastructure projects, allowing planning for rain delays;
- Emergency services, assisting logistics planning and preparedness for likely extreme events; and
- Tourism, through planning capacity and services for likely warmer/cooler than normal seasons.

The limits to skill and the inherent uncertainty of seasonal forecasts are not yet well understood by end users, and user expectations of potential improvements in forecasts may be higher or lower than can be achieved. Seasonal forecasts will be most valuable and informative if their uncertainty is well-understood, well-communicated and well-used. Education of end-users in the best use of forecast probabilities is essential, and end-user participation in the development of the information products derived from the forecasting model, whether statistical or dynamical, provides considerable benefit.

Climate forecasts at their current skill levels have been estimated to deliver a net benefit to agricultural production in Australia of 3-10%. The current skill of seasonal forecasts in most regions is only moderate, however, and varies throughout the year. Further, the probabilistic terms in which they are often expressed has led to a fairly widespread lack of confidence in using them for practical decision making. Consequently, some 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 presently 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 perceived benefit identified so far by 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 thus 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 gains from climate forecasts. For example, sugar millers in Queensland use 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 predictions. 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 could 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 and the Centre for Australian Weather and Climate Research (CAWCR) are developing 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 modelling approach is planned whereby the outputs from dynamic climate models described earlier will be downscaled to provide the inputs to hydrological models of various degrees of complexity.

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. 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 ensure optimum 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 contained in seasonal forecasts.

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 extreme events. Seasonal forecasting cannot provide prescriptive forecasts of specific events but can improve significantly our knowledge of the likely occurrence during coming seasons of meteorological conditions conducive to extreme events such as fire or flood. Such forecasts facilitate strategic planning and response logistics and provide advanced warning for emergency agencies, industry, and the community.

Emergency management practice has moved from simply planning to respond efficiently 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. Skilful longer term and inter-seasonal meteorological forecasting will further underpin 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 and their impact on the environment (e.g. fuel state for bushfires) in the coming season allows disaster mitigation preparation to better focus on the more likely threats. This approach assists emergency service organisations through targeted 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 to emergency management planning processes and emergency services responses. Improved seasonal forecasting assists the Bureau in the provision of early warnings of severe events conducive to severe conditions, including fire, heatwaves, tropical cyclones, severe storms and floods.

Better forecasts of conditions favourable for example to droughts, prolonged heavy rain, the occurrence of tropical cyclones, bushfire risk, a few weeks to months in advance would provide considerable socio-economic benefit for Australia (and for most Pacific Islands and Territories as well as Asian countries to the north of Australia) in planning to mitigate potential natural disasters. Extreme weather and climate have had a very high impact especially on small island nations (including on their GDP), where often the impacts of natural disasters are nation-wide. Through collaboration between the Bureau of Meteorology and AusAID, the small island developing states of the SW Pacific are benefiting 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 affecting 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.

Each year, the Bureau of Meteorology delivers pre-season Tropical Cyclone briefings and awareness campaigns 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 a coming season. The information is particularly important for remote and indigenous communities that could be isolated by flooding for relatively long periods. There are also particular demands for seasonal outlook services (or risk assessments) from the resource rich areas of Western Australia and the Northern Territory.

The Bureau has recently led the development of a rehabilitated tropical cyclone archive for the Australian Region which also extends to the Southern Hemisphere as a whole. These data have supported a number of significant analyses of the behaviour of historical tropical cyclone variability and trends and the links in their behaviour to large scale climate drivers like El Niño. There is substantial evidence from these and previous studies that the areas where tropical cyclones are more likely to occur are predictable on seasonal timescales.

Seasonal Tropical Cyclone Outlooks are currently issued at the beginning of every cyclone season for northern Australia. New systems are being developed that could improve these services. Cyclone outlooks are also occasionally updated during the season; for example, in the 2007/08 cyclone season, the Bureau issued advice of a potential Christmas/New Year tropical cyclone three weeks before the advent of Tropical Cyclone 'Helen' in Darwin. This advice was based on routine monitoring of intra-seasonal patterns across the tropics.

Aside from tropical cyclones, tropical intra-seasonal forecasting has also been demonstrated to have skill for monsoon and rainy season onset timing.

As noted earlier in this submission, the POAMA dynamical forecast model being developed jointly by the Bureau of Meteorology and CSIRO has demonstrated skill in predicting variations in the tropical climate, particularly associated with the El Niño-Southern Oscillation. There is reason to expect that further enhancement of this model and its utilisation for delivering seasonal forecasts will have flow on effects for improving the skill in prediction of tropical cyclone activity.

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. 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 a trend to increasing fire danger in SE and SW Australia.

Prescribed burning programs are used to mitigate the risk of wildfires. The annual window of opportunity during which prescribed burning can be completed safely, however, appears to be narrowing. A challenge is to develop 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 at times when current prescription rules fail to account for unusual weather events.

There is substantial evidence that bushfire season duration and severity is predictable using links to seasonal climate variability such as El Niño. Tropical intra-seasonal forecasting also has demonstrated skill in forecasting dry-season (winter) low-level wind patterns over northern Australia which could be incorporated into bushfire management processes. Advance warning of severe or benign fire seasons is a very real possibility, which also provides potential to manage fuels and preparedness outside the fire season.

At present, the seasonal information provided to fire managers only qualitatively deals with the potential for bushfire risk. Partly this stems from influences beyond climate variability, but it is also a function of the limitations in temporal resolution, skill and measures of the risks of extremes in current seasonal prediction products. New methods for displaying probabilistic seasonal forecasts have recently been developed by the Bureau, including the probabilities of exceeding certain rainfall thresholds and outlook scenarios at different probabilities. These offer more intuitive ways of viewing outlooks in a probabilistic framework. However, in order to provide more useful information to fire managers, a much wider range of products and delivery methods are required. Dynamic models such as POAMA offer the only feasible means of achieving these outcomes.

The Bureau's NCC aims to use the outputs of the POAMA dynamic seasonal forecasting model, once its utility is proven, to enhance the value and robustness of seasonal bushfire outlooks. The enhanced service offers the possibility of more accurate, longer lead-time forecasts, the development of fully objective forecasts for seasonal fire weather, and a much wider range of forecast products, including fire season severity and duration and risks of climate extremes.

Emergency managers, local government, and residents would also benefit 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 an ensemble of seasonal forecasts would provide seasonal probabilities of increased or decreased likelihood of floods.

Tsunamis are triggered by non-meteorological processes such as earthquakes in the ocean floor, submarine volcanic eruptions, or large landslides into the sea. Once a triggering event occurs, any tsunami generated will likely reach land within two days. There are no techniques available to reliably predict events that would trigger the occurrence of a tsunami on any time scale.

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

Summary: Australia's seasonal forecasts depend greatly on international observation systems, such as satellites, and benefit considerably from weather and climate forecasting technology developments in other countries. Australia's next generation forecasting systems are being built from model components originally developed in the USA and Europe. National capacity to adapt and further develop forecasting technologies is essential owing to Australia's vulnerability to climate variations specific to our region and the need to focus on the forecasting of Southern Hemisphere phenomena which may not be the highest priority for northern hemisphere nations.

The science and infrastructure required for predicting weather and climate are global in scope. Dynamical weather and climate forecasts for Australia are dependent on data obtained from satellites owned by other countries, especially Japan, US, Europe, China and Taiwan. 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 open ocean sea level.

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. Smart systems and better use of existing and expected data streams will help realise the full potential of weather and seasonal climate forecasting and allow forecasts to be made at smaller spatial scales with reliability over longer lead times. Australia will need to continue to engage with the international research and forecasting communities, especially where new technologies are being developed to improve both short and long-term forecasting. Strong engagement by the Australian science community in international meteorological and related programs is needed to ensure that Australia has early access to new technologies for which there is insufficient local development capacity.

Maintaining agreements for sharing weather and climate data with other countries is governed by the World Meteorological Organization (WMO) Convention. There are similar arrangements in place for the exchange of oceanographic and hydrological data and these arrangements will need to be extended as more data are required to initialise both weather and climate prediction models. Collaboration and engagement will also be required in the development and use of 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, so international agreements are crucial for global progress, including for operational monitoring and baseline measurements of atmospheric levels of greenhouse gases. Other international programs include: various WMO related activities for the science, forecasting and mitigation of tropical cyclones, monsoons, air quality; the World Weather Research Program (WWRP) for forecast system improvements (e.g., Sydney, Beijing, the upcoming Winter Olympics are catalysts for programs that involve multiple countries improving forecast systems); and international programs such as the Global Energy and Water Cycle Experiment (GEWEX) that aim to improve predictive capability for hydrological systems.

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, which 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 crucial for Pacific and El Niño and Indian Ocean Dipole forecasting systems (Australia makes no contribution but has access to the data by virtue of other collaborations);
- 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.