Submission to the House of Representatives Industry, Science and Innovation Committee *Inquiry into Long-term Meteorological Forecasting in Australia*

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* This submission is made in my capacity as an independent researcher and does not necessarily represent the views of Monash University.

This submission:

1. Outlines the history of science-based seasonal-to-interannual climate prediction (also known as "long-range weather forecasting") in Australia.
2. Outlines how the El Niño – Southern Oscillation provides a scientific basis for climate forecasting.
3. Outlines the barriers to increasing the skill of these forecasts.
4. Suggests approaches that could lead to improved skill and utility of the forecasts.

Summary of my expertise in the field

I have been undertaking scientific research into the nature, causes, impacts and predictability of climate variations and change since 1972. Up to 2005 I was a research scientist with the Bureau of Meteorology; I am now an Australian Research Council Professorial Fellow at Monash University. For my last 20 years with the Bureau I led the long-range/climate forecasting research group. I was a Lead Author for the Intergovernmental Panel on Climate Change's Fourth Assessment of climate change (2007). I have published over 100 peer-reviewed scientific journal papers about the causes, predictability, and impacts of climate variations and change. I was an editor of the American Meteorological Society's *Journal of Climate* for six years, and am now an Executive Editor of a new journal *Wiley Interdisciplinary Reviews: Climate Change*. In 2005 the UK's Royal Meteorological Society awarded me their Fitzroy Prize, for "distinguished work in applied meteorology". I am vice-president of the Australian Meteorological and Oceanography Society.

Focus of my comments

I wish to comment on all the terms of reference of this Inquiry. In order to understand and comment on the future of climate modelling and prediction it is important to commence with an understanding of how we reached our current state and abilities. It is also important to place climate modelling using complex computer models in the context of other approaches to climate prediction – especially statistical approaches.

The current operational climate forecast system available in Australia is based on the El Niño – Southern Oscillation. This natural mode of climate variability causes droughts and floods in many parts of the world, including much of Australia. It is caused by ocean-atmosphere interaction in the equatorial Pacific Ocean. In Australia it led to droughts in 1972, 1982, 1997, and 2001. Even the drought that hit Sydney in the late 18th century was caused by an El Niño event (Nicholls, 1988a; http://www.bom.gov.au/quarterly-focus/index.shtml).

Australia is a land of "droughts and flooding rains" because of the influence of the El Niño – Southern Oscillation, which exacerbates rainfall variability (Nicholls, 1988b; Nicholls and Wong, 1990). Unless our knowledge of this phenomenon is used to provide farmers with forecasts of the likely climate in the coming seasons, then they face an extra impediment to successful and profitable farming, relative to farmers in countries with less variable climates. Other climate phenomena also appear to influence Australia's climate, and including these in improved forecast systems should lead to more valuable and useful long-range forecasts.

Brief history of the development of operational inter-seasonal climate prediction for Australia

When I commenced climate research in the early 1970s it was widely accepted in the meteorological community that useful prediction on seasonal to interannual time scales was impossible. This was despite the fact that early in the 20th century a few researchers, within Australia and overseas, had identified the phenomenon that now provides the basis for Australia's operational seasonal climate forecast schemes - the El Niño – Southern Oscillation (Walker, 1910; Quayle, 1929; Treloar, 1934). Other possible approaches to climate prediction (use of sunspot cycles, for instance) had been tested and discarded as unpromising.

In the late 1970s, testing on modern data confirmed that the statistical relationships between Australian rainfall and the El Niño – Southern Oscillation that had first been reported in the early decades of the 20th century were still valid, and could provide the basis for a climate forecast scheme (Nicholls and Woodcock, 1981). Further research showed that a similar approach could be used to predict seasonal tropical cyclone activity (Nicholls, 1979), and the date of onset of the wet season in northern Australia (Nicholls et al., 1982) and Indonesia (Nicholls, 1981). During 1981, the Bureau considered whether to introduce an operational climate forecast system based on this research; at that time, no country had developed such a scientifically-based, long-range forecast system. The Bureau decided against issuing these forecasts at that time, because there were still concerns that the El Niño – Southern Oscillation was insufficiently understood and because the forecasts were only skilful in certain locations and seasons. The system would have predicted the severe drought associated with the 1982 El Niño, as well as other Australian droughts (Nicholls, 1983; Nicholls, 1985). Earlier work (Nicholls, 1973) had shown that droughts in Papua New Guinea were also related to the El Niño – Southern Oscillation.

By the late 1980s, a greater understanding of the mechanisms involved in the El Niño – Southern Oscillation had been developed, the first computer model of the phenomenon had been developed in the USA, and the Bureau felt justified in introducing an operational statistical forecast scheme, based on this phenomenon and its documented impacts on Australian climate variations. Operational forecasts were released by the Bureau's National Climate Centre from 1989, based on the statistical relationships between indices of the El Niño – Southern Oscillation and subsequent Australian rainfall.

Around the same time, colleagues in the Queensland Department of Primary Industries developed other statistical systems for seasonal climate prediction, based on the "phase" of the El Niño – Southern Oscillation (Stone and Auliciems, 1992; Stone et al., 1994), and cooperation between Queensland scientists and scientists from the Bureau of Meteorology led to refinements in the forecast systems.

Why does the El Niño – Southern Oscillation provide the basis for seasonal climate prediction?

There are three reasons why this phenomenon allows the production of skilful seasonal climate forecasts (Nicholls, 1991).

- El Niño events tend to cause dry conditions in eastern & northern Australia.
- El Niño events tend to last about 12 months.
- El Niño events tend to start around March/April.

This means that if in early winter we recognise that an El Niño event is underway, then we can forecast that below average rainfall is likely through late winter, spring and summer in eastern and northern Australia (as well as much of Indonesia and Papua New Guinea). In other areas (notably the eastern equatorial Pacific), more rainfall than normal is received during an El Niño event.

However, a major limitation with forecasts based on the El Niño – Southern Oscillation is that prediction across March/April (eg., of early winter rainfall) is very difficult, because this is the time that El Niño events are starting to develop but may not yet be sufficiently strong to be observed. This is known as the "autumn predictability barrier", and its causes are still not understood.

How did the forecast system develop through the subsequent years?

Initially the forecast system was quite simple, and based on the so-called Southern Oscillation Index (SOI), the difference in pressure between Tahiti and Darwin. Forecasts were only issued for regions and seasons where the research had indicated that good skill was achievable – areas and seasons where the skill was low were omitted from the forecasts. After research linking sea surface temperature (SST) anomalies to Australian rainfall (Nicholls, 1989) suggested that better forecasts might be achieved by replacing the SOI with observed SSTs from the Indian and Pacific Oceans, a new operational statistical forecast scheme was developed (Drosdowsky and Chambers, 2001) and introduced in the late 1990s. By this time forecasts were being issued for all seasons and parts of Australia, even though forecasts in some seasons and regions were expected to exhibit quite low skill.

By the mid-1990s, the forecasts were being expressed in probabilistic terms (eg, "there is a 60% chance of drier than normal conditions over the next three months"), to ensure that forecast users recognised that the climate system is to some extent chaotic. If used correctly, research had shown that these forecasts, even with limited skill, could be useful for farmers (Hammer et al, 2000).

Later, the statistical forecasts were supplemented by the use of coupled ocean-atmosphere models that had been developed through the late 1980s and 1990s. These could be used to predict whether an El Ninõ event was likely to develop. But the statistical relationships between SSTs and subsequent rainfall (and temperature) still provide the foundation of the operational seasonal rainfall and temperature forecasts for Australia (and for some countries in the South Pacific and elsewhere).

Queensland government scientists and Bureau of Meteorology scientists collaborated to develop software (RAINMAN) that could be used by individual farmers and others to investigate whether seasonal predictions might be useful for specific locations and seasons and for specific, farm-centred decision-making – in a sense to use the El Niño – Southern Oscillation in "do-it-yourself climate prediction" (Clewett et al., 1994, 1999). The information required to use RAINMAN came from El Niño – Southern Oscillation monitoring and forecasts produced by the Bureau of Meteorology and Queensland Department of Primary Industries. Videos and booklets (eg., Bureau of Meteorology, 1994) helped farmers understand the El Niño – Southern Oscillation and how to use forecasts based on the phenomenon.

The above is a very brief introduction to the development of scientific climate prediction in Australia and elsewhere. A more detailed account is given in Nicholls (2005).

Problems with the operational seasonal forecast system

A major limitation of forecasts based the El Niño – Southern Oscillation is the "autumn predictability barrier". This means that forecasts of autumn and early winter rainfall are unreliable. Since many farmers rely on early season rainfall to make important decisions on planting, the forecast system is not as useful as it would be if a technique to forecast early season rainfall could be developed.

A second problem that has developed over the last two decades is that climate change is gradually altering the relationships between indices of the El Niño – Southern Oscillation and Australian temperature and rainfall (Nicholls et al., 1996; Nicholls, 2008). As a result, forecasts based on historical data will be biased, and this bias is likely to increase in the future. Thus Australian temperatures have increased since the middle of the 20th century, in concert with similar warming throughout the world. Forecasts based on data from several decades ago will therefore be biased cool, if this warming is not taken into account.

Recent work (eg., Ummenhofer et al, 2008; Nicholls, 2009) has revealed other possible Indian Ocean (and Southern Ocean) influences on Australian rainfall. Inclusion of predictors reflecting these influences might lead to better predictions.

Ways to improve Australian seasonal forecasting

More than thirty years of research has shown that variations in Australian rainfall and temperature from year-to-year are predictable, with generally useful skill, in some areas and at certain times of the year. These forecasts, if used sensibly, can help farmers and others (eg., the early prediction of national crop yields through monitoring indices of the El Niño – Southern Oscillation can help national financial planning, and forecasts of heavier than normal rainfall can help health authorities concerned with epidemics of Ross River virus or Australian Encephalitis). However, the limitations in the skill of these forecasts need to be recognised and considered in decision-making based on the forecasts. Improvement of the forecasts is feasible, but they will remain short of "perfect" forecasts.

The statistical relationships between indices of the El Niño – Southern Oscillation and subsequent rainfall and temperature remain the core of the operational seasonal climate forecast system, despite the problems noted above and the fact that the statistical forecast system is now quite old. If the system is to be improved, and be more useful to farmers and others, the following could be undertaken:

- Re-engineer the operational forecast system run by the Bureau of Meteorology, to include new data that have become available since its initial introduction in the mid-1990s, and utilizing more modern statistical approaches.
- Re-engineer the system to include recent research on climate factors, other than the El Niño – Southern Oscillation and the Indian Ocean sea surface temperature patterns, affecting Australian rainfall.
- Develop a system that takes into account the long-term changes in Australian temperature and rainfall, and changes in the behaviour of the El Niño – Southern Oscillation, to avoid bias due to our changing climate.
- Develop a system that allows useful prediction across the "autumn predictability barrier". This will require more research on the causes of the barrier and methods to circumvent it.
- Provide sustained funding for the development of dynamical and empirical seasonal-to-interannual forecast systems, and their application.

Ultimately, the statistical forecast system will be replaced by improved coupled ocean-atmosphere models, capable of direct prediction of rainfall and temperature over Australia, so work is required to continue the development and improvement of these models, in parallel with the re-engineering of the statistical forecast system.

Concluding remarks

Australia's operational climate forecasting systems are based on the work, a couple of decades ago, of a few scientists in the Bureau of Meteorology and Queensland Department of Primary Industries who had the security and resources to pursue innovative research on this challenging topic. More recently, the development of improved forecast systems has relied on short-term research contracts from a variety of agencies. These funding agencies have little interest in the development of an improved national forecast system, because of their very specific geographical and sector foci. The recognition that reliance on such a fragmented approach would not lead to improved forecast systems led to proposals to establish a national centre or institute or funding mechanism dedicated to the development and application of improved seasonal-to-interannual climate forecasts. Despite several such proposals, such an enterprise has not materialized.

On the other hand, thirteen years ago the USA established just such an enterprise, the multi-million dollar research institute (the *International Research Institute for Climate and Society*, or IRI) aimed at developing and using seasonal-to-interannual forecast methods to "enhance society's capability to understand, anticipate and manage the impacts of seasonal climate fluctuations in order to improve human welfare". The establishment of the IRI was based, in part, on the successful use of climate predictions in Australia, and an Australian scientist still serves on the IRI's Scientific and Technical Advisory Committee. Other countries have also invested heavily in such research, and provided long-term core funding. The IRI is now the world leader in this field, and Australia's performance has fallen behind world-best-practice.

The simplest strategy to ensure that Australia develops innovative and improved approaches to increase our ability to forecast seasonal-to-interannual climate fluctuations such as droughts, and to use such forecasts effectively, is to establish a centre of excellence or a CRC with long-term (more than seven years) funding and dedicated staff and resources. Such a centre would combine the expertise of climate researchers in universities, the CSIRO, the Bureau of Meteorology, and various State Government bodies in a collaborative approach to this challenging problem. The alternative, current approach, of competitive bidding by individual researchers for small, short-term research grants militates against collaboration between agencies and universities, and is ineffective in the development of the complex systems needed for operational climate prediction.

Continued reliance on a fragmented approach to funding Australian research on seasonal-to-interannual climate prediction will ensure that Australia's performance in this field continues to slip relative to other countries, where climate prediction research is more effectively resourced. Eventually, this fragmented approach will ensure that Australia becomes reliant on other countries to provide the systems and models for prediction, and probably even the forecasts themselves.

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