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Submission to the House of Representatives Industry, Science and Innovation Committee *Inquiry into Long-term Meteorological Forecasting in Australia* from the Australian Meteorological & Oceanographic Society (AMOS).

Background: What is AMOS?

AMOS is an independent Australian professional society that supports and fosters interest in meteorology, oceanography and other related sciences. The Society helps all those with an interest in the environment including research workers and professionals, and those whose work is affected by, and affects, the atmosphere and oceans. It provides support and fosters interest in meteorology and oceanography through its publications, meetings, courses, grants and prizes, and represents the views of its members to Government, institutes and the public. The Society's 500+ members include weather observers and forecasters, weather and climate researchers in universities and government research bodies, consultants, and teachers. More details about the Society and its publications are available at www.amos.org.au.

Scope of this submission

This submission addresses all the Terms of Reference of the Inquiry, and commences with a brief overview of the role of computer models in weather forecasting and climate prediction.

An overview of computer models for meteorology

Computer models of the atmosphere-ocean-cryosphere-land system are essential tools for modern weather forecasting, climate change projections, and for prediction of climate variations from year-to-year. Although the essential ingredients of weather and climate forecasting models are the same (the equations representing the laws of motion, conservation of mass, etc, and the methods of integrating these equations to produce forecasts of future behaviour) the ways the models use these fundamental equations differ somewhat according to the various usages of the models.

Weather forecasting models solve the fundamental equations on very high-resolution spatial representations of the atmosphere. However, because of the short-term nature of these forecasts (usually from 1-10 days), the way in which the atmosphere interacts with the ocean and land surface can be simplified (and feedbacks from these other two components of the earth system can be ignored). Despite these simplifications, weather forecast models require powerful computing resources, to allow the production of the forecasts in a timely manner. They also require highly detailed analyses of the current atmospheric situation across the entire globe, in order to realistically initialise the models.

Very similar models, based on the same equations, are used in climate change projections to, for instance, determine the likely effect of increasing the atmospheric content of greenhouse gases such as carbon dioxide, or to diagnose the effects of massive volcanic eruptions. In this climate mode the models are integrated for very long periods, so that the model output can be averaged over many years to provide an estimate of the future climate. Because of the need for very long integrations, and because computing resources are limited, the models operate at lower spatial resolution than weather forecasting versions of the same models. However, over the very long periods of integration, feedbacks between the components of the earth system are important, so the ability for the models to simulate coupling between the atmosphere, ocean, snow and ice, and land, is required. As well, changes in factors that "force" the atmosphere such as the chemical composition of the atmosphere, or changes in solar forcing, or even changes in continental distributions across the earth's surface, are generally included. These versions of the models are very heavy users of computing resources but, in general, their mode of usage allows very long periods in which to run the models (compared with their usage in weather forecasting where time is of the essence).

The third use of computer models, and the usage addressed by this Inquiry, regards their use in predicting climate variations for the next season or year (termed "seasonal to interannual prediction" or "long-range weather forecasting"). Attempts are also underway to produce forecasts on the decadal (ten years or so) time-scale. In this usage, the level of complexity of the models lies somewhere between that used in weather forecasting and that used in climate change predictions). This is required because long integrations of the models are required for this time scale, but these integrations need to be carried out quickly enough to allow real-time forecasting of the climate of the next month or season. As a result, the spatial resolution of the models is less detailed and the models tend to focus on specific forms of ocean-atmosphere interaction, especially those involved in the development of the El Niño – Southern Oscillation. The focus is on natural climate variations, rather than long-term changes in the climate system, such as those induced by human activity, although realistic concentrations of greenhouse gases are imposed on the model atmosphere.

In all three modes of operation of these models, multiple integrations starting from slightly different initial conditions are now the norm. This is to allow a better understanding of the uncertainties likely to arise from the initial conditions and the somewhat chaotic nature of the earth system.

It should be noted that empirical, statistical methods are also used in prediction of the climate at these seasonal to interannual time scales, eg., by the Bureau of Meteorology in its operational seasonal rainfall and temperature predictions. These methods provide very important information on the likely behaviour of the climate system, but are not discussed further in this Submission.

Responses to the Terms of Inquiry

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

The future of long-term meteorological prediction is closely tied to the development and use of the computer models described above. They provide the only viable path likely to lead to substantially improved forecast skill, although statistical techniques may continue to supplement modeling efforts. There is now a trend in the international community to design so-called seamless prediction systems, in which the same computer models (with the varying degree of complexity described above) are applied to predictions at all time-scales ranging from days (weather) to seasons to decades to climate change. It is likely that such systems will be employed in most major national weather and climate services within the next decade.

Australia possesses a close to state-of-the-art computer modeling system for seasonal to interannual prediction, the Predictive Ocean Atmosphere Model for Australia (POAMA). POAMA is the combination of a coupled ocean/ atmosphere computer model linked to ocean/atmosphere/land observation assimilation systems. The system was developed by CSIRO and the Bureau of Meteorology. Version 1 of POAMA commenced producing forecasts of El Niño conditions in 2002. Subsequent work has refined the model. POAMA delivers forecasts of El Niño conditions at long lead times. POAMA, and similar models developed overseas, couple the ocean and atmosphere and can use all the latest observations from ships, satellites, ground observations etc to construct a picture of what the ocean, land and atmosphere look like today. A picture of how the state of the ocean, land and atmosphere is evolving is then generated using the coupled model. Unlike statistical climate forecasting systems, coupled models are not limited by historical relationships and can forecast a new set of climatic conditions. For example, they have the potential to predict how the impacts of one El Niño might be different to those of another. One of the benefits of coupled models is that many forecasts (an ensemble) can be produced. If these are all close together then we can have confidence in the forecast. If they all differ significantly they can tell us that there is considerable uncertainty in the future and they give us the range of possibilities.

Each day a new POAMA forecast is produced. The ocean, atmosphere and land surface are initialized with the latest observations of the ocean surface temperature, for instance. The POAMA model is then run to simulate the ocean and atmosphere conditions of the next nine months. Each daily forecast therefore differs slightly because of the initial state of the climate system. The variability of the results among forecasts gives an indication of the uncertainty in the future evolution of the climate system. When many individual forecasts are considered together they are said to comprise an *ensemble* and the spread in the conditions they forecast can be used to quantify the *probability distribution* of future conditions. Generally the outlooks provided by POAMA are based on an ensemble of the 30 most recent POAMA forecasts. The start dates of each of these 30 forecasts are one day apart. More detail about POAMA and its forecasts are available at http://poama.bom.gov.au

Compared to weather forecasting, coupled model seasonal forecasting is still in its infancy. However, these models do exhibit real skill in predicting variations in sea surface temperature such as those associated with the El Niño. A discussion of the skill of POAMA is available at http://www.bom.gov.au/bmrc/pubs/researchletter/reslett_08.pdf, based on a study of how the model performed on 27 past years in so-called "hindcast" mode.

Farmers recognize the potential value of seasonal climate predictions, even with their current, limited level of skill. A 2002 survey of 2000 farmers, commissioned by the

Department of Agriculture, Fisheries and Forestry, found that over 40% of farmers take seasonal climate forecasts into account in farm decisions (http://products.lwa.gov.au/files/PN050834.pdf).

Australia has recently commenced building a prediction system for all time-scales through the Australian Community Climate and Earth System Simulator (ACCESS) project. The project is a collaborative effort between the Bureau of Meteorology, CSIRO and the Australian University community. ACCESS is an ambitious project, requiring significant resources as well as a nationally coordinated research effort. There has been progress in the use of the ACCESS system in weather prediction as well as climate projection. However, limited human and computational resources continue to hamper efforts in using the system seamlessly and in particular in the long-range predictions that are the subject of this inquiry. A significant increase in resources, both human and computational, is required to stay abreast of the international community and to provide Australia with a prediction system that is state-of-the art, well supported and can meet society's demand for information on future weather and climate.

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

Considerable research has been undertaken to investigate how agriculture and other sectors could best use the skill inherent in current seasonal climate prediction (Hammer et al., 2000, *Applications of seasonal climate forecasting in agricultural and natural ecosystems. The Australian experience*, Kluwer, 482pp). The results of this research indicates that many sectors can profitably use predictions of seasonal to interannual climate with their current levels of skill, as long as the forecast information is interpreted correctly and included in an appropriate decision-making scheme. It is important that the information provided about the confidence in the forecasts, which are expressed as probabilities, is taken seriously – the forecasts, although exhibiting skill, should not be assumed to be perfect. In this way they can be considered in the same way as decision-makers use other forecast information, such as projections of interest rates, and prices of inputs and outputs. The value of current operational seasonal climate forecasts in agriculture has been assessed by Land & Water Australia (http://products.lwa.gov.au/files/PN040792.pdf).

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

These models produce forecasts of the likely state of the El Niño – Southern Oscillation, and other patterns of sea surface temperature known to be related to Australian climate variations. Known statistical relationships between these sea surface temperature patterns and Australian climate can then be used to predict how the rainfall and temperature of the coming season may differ from the normal for that time of the year. Similarly, because the number of tropical cyclones observed around northern Australia across summer is known to be related to the pattern of sea surface temperature, the amount of cyclone activity to be expected over a cyclone season can also be predicted with some skill (although the ability to predict individual tropical cyclones on these timescales remains elusive and challenging).

These predictions of seasonal rainfall, temperature, and tropical cyclone activity can be used to improve preparations for emergency response activities. Thus, a prediction of a dry spring and summer in Victoria might be used to trigger increased efforts at public education regarding the likelihood of fires (whereas in a season where increased rainfall is expected such public education might be reduced). Similarly, a prediction of a hot summer might allow health services to plan for an enhanced response in the case of more extreme heat waves. The use of the seasonal forecasts for such planning should improve emergency response to acute emergencies such as fire and heat waves.

These models can also be used to provide the basis for seasonal climate forecasts over much of the South Pacific and southeast Asia, and could be used in these regions for similar purposes, to improve the state of preparation of emergency services in years predicted to have dangerous climate situations.

Seasonal predictions of sea surface temperatures (SSTs) from these models are also of value for Australia's tropical coral reef ecosystems and the goods and services they provide. Unusually warm SSTs during summer can lead to "coral bleaching" as happened in ed large parts of the Great Barrier Reef (GBR) in 1998, 2002 and 2006 with flow-on effects to other organisms and, importantly, the perceived tourist attraction of the reef. POAMA has recently been producing experimental predictions of the likelihood of unusually warm GBR SSTs during the upcoming summer season. These products are of value to ecosystem managers and users of the reef and need to be refined and expanded to encompass all Australia's coral reef ecosystems. In the future these products need to be improved to include, for example, predictions of the likelihood and locations of tropical cyclones, which can have significant cooling effects and thus reduce the chances of thermal stress to corals but can result in significant physical damage to coral reefs.

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

Australia has a long history in developing and applying computer models of the atmosphere-ocean system for prediction on time scales from weather to climate change. However, much of this development has been done using limited resources, especially super-computing resources. Meteorological computer models, ranging from those used in daily weather production to those used in seasonal climate prediction and climate change projections, all require very large investments in computing capabilities, and the availability of supercomputers. Access to supercomputing facilities by the Australian scientists developing and running these models is limited relative to those available to overseas scientists in America, Europe, and, increasingly through Asia (eg., China, India, Singapore and South Korea). The relative inferiority of supercomputer resources available to Australian scientists necessarily restricts the quality of the models run here and the quality of the forecasts available from these models. Although new supercomputers have just been provided to the Bureau of Meteorology and the Australian National University (http://www.bom.gov.au/announcements/media_releases/ho/20090319.shtml), these new computers will still leave Australia far behind the resources available in comparable countries.

As well as adequate computing facilities, the development and operation of computer models requires dedicated staffing. Declining numbers of Australian scientists employed by the Bureau of Meteorology and CSIRO in the development of these computer models means that the Australian development of models struggles to maintain international competitiveness. To some extent the decline in the number of Australian scientists focussed on model development has been offset by “importing” models from overseas, but this increases Australian reliance on overseas scientists to maintain these models. Nor does this reduce the requirement to evaluate the performance of all models in the Australian context, and this requires sufficient numbers of well-trained scientists in Australian government meteorological research laboratories (Bureau of Meteorology and CSIRO) and suitably trained students emerging from the university sector. The decline in the numbers of Bureau and CSIRO scientists involved in modelling has also been offset through the use of short-term contracts available through rural research bodies and other short-term research funding mechanisms. However, the short-term nature and focus of these funding bodies has meant that the long-term focus required for continued model development and improvement is difficult to maintain. This lack of strategic planning and funding in seasonal climate prediction research and development has also had the effect of producing a fragmented effort, with agencies and individuals competing for the limited funds without a clear vision of how their individual efforts can contribute to the overall improvement of Australian seasonal climate prediction capacity. Without an increase in dedicated, long-term staffing to focus on development and maintenance of these models, and to offset the decline in such staff over past decades, any progress in Australian model development and forecasting skill is likely to be modest.

Improved collaboration with overseas agencies involved in development and application of computer models for seasonal-to-interannual climate prediction would bring benefits to Australia. Such collaboration would, for instance, allow the use of a much larger suite of models and model predictions, which would lead to a better estimate of the uncertainties in these forecasts. However, there is much that is of specific interest to Australian users of climate predictions that is of less interest to potential collaborators overseas. For instance, the lower predictability that is evident around the southern hemisphere autumn is of critical importance in limiting the utility of current climate forecasts in agriculture. This is of less concern to northern hemisphere farmers. So, over-reliance on overseas institutions to develop forecast systems would lead to forecasts that are less specific to Australia, and hence less useful.

Conclusions

The future of long-term forecasting lies in improved applications of computer models, which will mainly result from improvements in the models themselves and from improved supercomputing capabilities for running these models. Although Australia does have climate modelling capabilities and, with POAMA, a model that is, at the moment, close to the state-of-the-art in seasonal prediction, a continuing decline in the supercomputing and human resources available for developing and running these models, relative to many overseas countries, threatens the continued availability of “world’s best practice” within this country. As well, current resources preclude the Australian community from involvement in major new developments in long-range forecasting, such as the emerging area of decadal prediction. Only a recognition of the need to provide adequate supercomputing resources, and the employment of permanent staff in the Bureau of Meteorology and CSIRO, as well as a well-coordinated national research program that embraces the academic sector, will ensure that Australian long-term prediction abilities remains close to “state-of-the-art” in the future.

Effective use of climate forecasts requires more than just the development of climate models (although such development is also critical). Research and experience over the past two decades has shown that effective use of the forecasts will only come through the development and implementation of an “end-to-end” approach to this problem. So, as well as model development and improved supercomputing resources to allow effective use of the models, improvements in data input to the models is required, as is improved understanding of the needs of potential users, and improved communication between users, model developers, and those issuing operational forecasts. Such an “end-to-end” system requires local knowledge, and cannot be left to overseas organizations and researchers.

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