South Eastern Australian
Climate initiative

Final Report Project 3.1.3

Simulation and potential predictability of SE Australia rainfall and temperature from the national dynamical seasonal prediction model

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Project Abstract

The Predictive Ocean Atmosphere Model for Australia (POAMA) is a state-of-the-art seasonal forecast system based on a coupled ocean/atmosphere model. POAMA was developed by the Bureau of Meteorology Research Centre and CSIRO Marine Research, with support from the Climate Variability in Agriculture Program, a consortium of rural research and development corporations managed by Land and Water Australia.

POAMA is used in real- time by the Bureau to produce an eight-month forecast every day (current forecasts and system information available at http://poama.bom.gov.au). One of the special features of POAMA is that it uses the very latest observations from global ocean and atmosphere observing systems, right up to the previous day. The work described here will lead to a detailed assessment of the predictive skill of the POAMA system for south-eastern Australia in simulation and forecast modes, and improved understanding of the key mechanisms and processes that lead to climate variability in the GRDC region.

Project objectives

- Determine the ability of the Bureau's climate/seasonal prediction models to simulate climate variability in south eastern Australia
- Determine potential predictability of climate variability, especially rainfall and surface temperature, in south eastern Australia

Methodology

- Assessment of the simulation skill of POAMA
- Assessment of the potential predictability of the primary modes of climate variability that drive rainfall and temperature in south-eastern Australia by using an ensemble of atmospheric climate model runs (the atmospheric component of POAMA) forced with climatological and observed sea surface temperature variations for the period 1981-2005
- Identification and assessment of the primary modes of climate variability that drive rainfall and temperature in south-eastern Australia using a extended run of the coupled climate version of POAMA and operational hindcasts from POAMA

Summary of the findings

- Analysis of an ensemble of simulations using the atmospheric model of POAMA forced by observed sea surface temperature (SST) variations for the period 1982-2002 indicates the upper limit of predictability for SE Australian rainfall is about 30%. Rainfall is most predictable in autumn-spring. This level of predictability is in line with estimates of observed predictability based on correlations with El Niño indices such as the Nino3 SST index or the Southern Oscillation Index.
- A portion of winter-spring rainfall predictability in the SE stems from sea surface temperature variations in the tropical eastern Indian Ocean. The sensitivity to eastern Indian Ocean SST points to the need to improve observations and initialization in the Indian Ocean in order to improve dynamical seasonal prediction.

- POAMA is found to have skill in predicting the major El Niño-related SST variations as well as some of the east-west SST shifts in individual El Niño events that have large impact on east Australian rainfall. POAMA was also found to simulate the major atmospheric teleconnections driven by El Niño and it captures the observed sensitivity to the east-west shifts of El Niño. Direct prediction of rainfall in SE Australia, however, is hampered by model drift and bias. The ability to predict El Niño and some of its details suggests skilful prediction of regional SE Australian climate might be possible via bridging/downscaling (project 3.2.2)

Methodology and Results

Objective 1: Potential Predictability of SE Australian Rainfall

Introduction

The Bureau of Meteorology routinely makes dynamical seasonal predictions out to 9 month lead time with the POAMA coupled ocean-atmosphere forecast system. POAMA (Predictive Ocean Atmosphere Model for Australia) is an intra-seasonal to inter-annual climate prediction system based on coupled ocean and atmosphere general circulation models. The original focus for POAMA-1 was the prediction of sea surface temperature (SST) anomalies associated with El Niño / La Niña, for which POAMA's predictions are internationally competitive. El Niño/Southern Oscillation (ENSO) is the dominant driver of Australian climate variability (e.g., McBride and Nicholls 1983), thus POAMA's forecasts have great value for anticipating the behavior of El Niño.

The POAMA system is continually evolving and improving, and subsequent versions of POAMA will address problematic bias and drift that hinder direct prediction of regional climate variations, such as rainfall and temperature across continental Australia. However, even assuming model drift and bias can be improved and that increased resolution leads to better regional climate simulation, the degree of predictability of regional climate is unknown. Perfect prediction of the slowly varying surface boundary forcing (primarily tropical sea surface temperatures; SST), which is thought to be the main source of seasonal climate predictability (e.g., Charney and Sukla 1981), will account for only a portion of actual climate variability due to the presence of internal atmospheric noise. Nonetheless, an assessment of the theoretical upper limit of predictability, given perfect knowledge of the slowly varying boundary forcing, will provide an upper bound on the expected skill of the POAMA system.

Methodology

To assess potential predictability of regional climate, we assume perfect knowledge of the slow variation of global tropical SST for the period 1982-2003. Effectively, we replace the ocean model component of POAMA with a prescription of the SST variation that actually occurred. To assess the relative roles of forcing from the Pacific and Indian Oceans SST, we conducted three additional experiments. In "Pacific large", observed SST variations are prescribed in the entire tropical Pacific Ocean, while climatological SST is prescribed elsewhere. In "Pacific small", observed SST is prescribed only in the eastern tropical Pacific Ocean. These two experiments are aimed at elucidating the global teleconnections that are driven by SST variations associated with El Niño/Southern Oscillation (ENSO). The Pacific small runs are aimed at understanding the forcing by SST variations in the main El Niño region of the equatorial eastern Pacific. The Pacific large runs include the SST forcing in the far western Pacific, where anomalies during ENSO tend to be out of phase with those in the eastern Pacific. The role of Indian Ocean SST is highlighted in the Indian experiment, where observed SST variations are prescribed only in the tropical Indian Ocean. In all cases, 8 ensemble members are generated for the period 1982-2003 using slightly different initial conditions and predictability is assessed following Rowell (1998).

Results

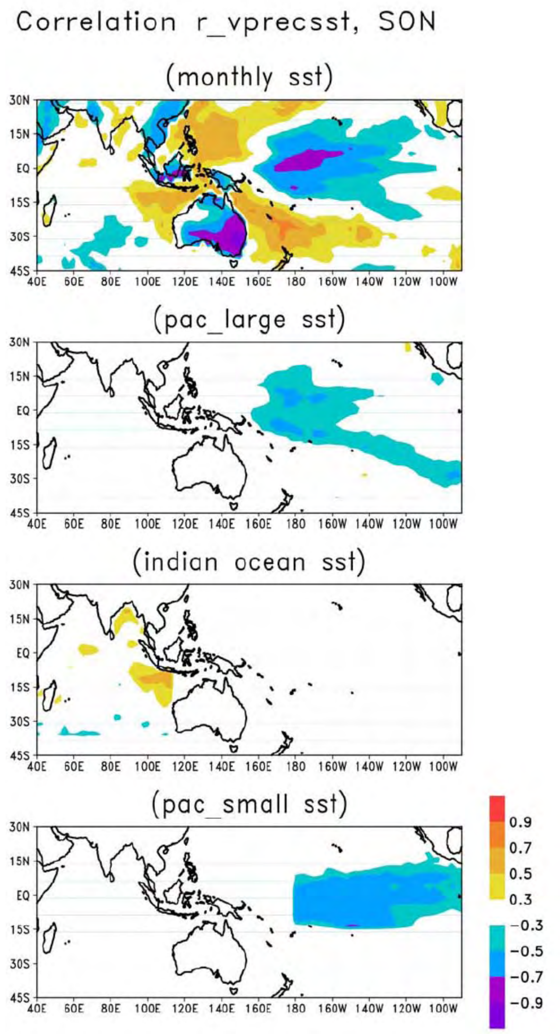

Fig 1. Correlation between simulated SON rainfall in SE Australia (area mean for point south of 32S) and SST for the (top-bottom) the model simulations forced by global SST, Pac large SST, Indian Ocean SST, and Pacific Small SST for the period 1982-2004.

Based on analysis of this suite of "perfect SST" experiments with POAMA seasonal forecasts system, SE Australian rainfall is found to be most predictable in autumn through spring, when up to 30% of the rainfall variance is predictable (Hendon et al. 2007a). That is, if we could perfectly predict global sea surface temperatures, the maximum amount of rainfall variability that we could expect to predict is about 30%. This estimate is an upper limit, as we know that we can never perfectly predict SST. Nonetheless, SST is highly predictable at short lead time. Therefore, 30% predictability should not be viewed as being unattainable. Nonetheless, the potential usefulness of 30% predictability of rainfall needs to be assessed. For instance, predictability of crop yield or stream flow could be assessed based on output from this ensemble of simulations, where both the predictable component and noise component of the climate is known and well sampled.

The estimation of potential predictability of SE Australian rainfall in this study, while highly dependent on the model that was used, is in line with the observed rainfall variance that is accounted for by El Niño, which is the dominant source of interannual variation of SST and of rainfall variability (e.g., McBride and Nicholls 1983; Drosdowsky and Chambers 1991). This study also confirms that the atmospheric model of POAMA realistically simulates climate variability over SE Australia that is forced by variations of tropical SST (Hendon et al. 2007a). That is, the sensitivity of simulated rainfall in SE Australia to tropical SST variations is very realistic. Interestingly, this study indicates that a significant portion of the predictable rainfall variability in the SE during spring and winter stems from SST variations in the tropical eastern Indian Ocean (Fig. 1), consistent with observations of rainfall variations associated with the Indian Ocean Dipole (e.g., Nicholls 1989; Meyers et al. 2007). This might appear to be counter to the notion that ENSO is the main driver of rainfall variability during these seasons. However, during ENSO SST anomalies co-vary in the Indian Ocean with those in the equatorial Pacific (Meyers et al. 2007) and it is this co-varying SST in the Indian Ocean that drives a significant portion of the predictable rainfall variations in the SE.

Conclusions

The atmospheric component of POAMA realistically simulates climate variability in SE Australia given perfect knowledge of tropical SST. Improvement of rainfall prediction in the SE from the POAMA system will require improved initialization and simulation of the topical oceans and in particular the Indian Ocean and reduction in model drift. Currently, model bias and lack of accurate initial oceanic and atmospheric conditions hinder the ability to predict the coupled-state of the Indian Ocean. However, improvements to the POAMA component models should alleviate some of the bias in the Indian Ocean (in particular, the overall cold SST bias and elevation of the thermocline in the eastern Indian Ocean). Furthermore, a new ocean assimilation system is nearing completion and will be part of the POAMA 2 system. This new assimilation scheme, which initializes salinity, temperature and currents, shows great promise for improved initialization of the Indian Ocean. Experiments to assess its impact on predictability of SE Australian climate will continue in Project 3.1.4

Objective 2: Simulation/prediction of primary modes of SE Australia climate variability

Introduction

Assessment of POAMA's ability to simulate the major modes of climate variability that are relevant to SE Australian climate is required to provide a benchmark for future improvements of the forecast systems, such as that anticipated by development of the ACCESS system (e.g., improved spatial resolution, improved physical parameterizations, and reduced model drift). This assessment is also required because the utility of the forecasts from the current version of POAMA is unknown. There is also scope for bridging and downscaling of the forecasts (Project 3.2.2), which is founded on the notion that important climate drivers (primarily ENSO and its teleconnections) are predicted faithfully. The focus of this study is not only on ENSO but also on other tropical sea surface temperature variations such as those in the equatorial eastern Indian Ocean that are important for SE Australian rainfall (e.g., Nicholls 1989; Meyers et al. 2007). We have also assessed the impact of model drift on these relationships, which should aide future development of the POAMA system.

Methodology

The primary modes of climate variability that drive rainfall variations in SE Australia were assessed in the 25 years of hindcasts (re-forecasts) from the POAMA seasonal forecasting system. In contrast to the model runs used in the first part of this study where SST were prescribed as observed, this second study use the fully coupled system which predicts both atmosphere and ocean conditions. The analysis here is based on a 3 member ensemble of 9-month forecasts for the period 1982-2006. Forecasts are initialized from observed atmospheric and ocean initial states. The atmospheric initial state, together with the land surface condition, is produced by the ALI system (details at http://poama.bom.gov.au). The ocean initial condition is provided by the ocean initialization system that piggybacks on the POAMA system. Forecasts are initialized on the first of each month. Three forecasts are made each month from slightly different atmospheric initial conditions but with identical oceanic initial conditions.

Results

We first assess POAMA's ability to simulate the major modes of SST variability that are relevant to Australian climate variability. Foremost is ENSO. However, Wang and Hendon (2007) emphasized that the eastern Australia rainfall is sensitive to the "inter-El Niño" variations of SST as well, which are the east-west shifts of SST anomalies in the central Pacific between different El Niño/La Niña events. For instance, the 1997 El Niño event had SST anomalies shifted well east in the Pacific while the 2002 El Niño was more concentrated in the central Pacific. Wang and Hendon (2007) showed that the springtime drought in 2002 could be accounted for by the westward shift of the El Niño, while the near normal spring in 1997 could be accounted for by the eastward shift.

The skill for prediction of the temporal variation of these leading modes of SST is assessed by the correlation of the predicted and observed El Niño and inter-El Niño patterns of SST variability (Hendon et al 2007b). In general, the ENSO mode is predictable out to at least 6 months, while the "inter-El Niño" variations are predictable for about 4-5 months. At short lead times, the spatial pattern of the SST variations in the forecasts is nearly identical to the observed patterns (Hendon et al. 2007b). At longer lead-times, some important drift in the leading patterns of SST variability occurs. The major drift is the extension of the warm anomaly associated with the El Niño all the way across the Pacific into Indonesia.

We then assessed POAMA's ability to simulate the teleconnection between the leading modes of tropical SST variability and Australian rainfall. The correlation of observed rainfall with the two leading patterns of observed tropical SST for the winter (JJA) season is shown in Fig 2 (middle panels). Correlations are generally negative across eastern Australia (warm SST in the central Pacific is associated with reduced rainfall in eastern Australia). But, rainfall in parts of central eastern Australia is more sensitive to the second mode of SST variation than to ENSO. The SEACI region is equally sensitive (Fig. 3). Similar sensitivity is seen in spring but then the ENSO mode is more dominant (Hendon et al. 2007b)

POAMA’s ability to simulate these relationships between rainfall and SST are shown in the panels around the perimeter of Figure 2 (as a function of forecast leadtime) and in Figure 3 for the SEACI region. The impact of model drift on the relationship with the ENSO mode is stunning. For instance, POAMA does a modestly good job representing the negative relationship on the east coast at short lead time (ie. reduced rainfall during El Niño). But, at longer lead-time, POAMA simulates exactly the wrong response (enhanced rainfall in the SE during El Niño). Model drift seems to be less of an issue for the inter-El Niño SST variations. Overall, though, the current version of POAMA appears to do a credible job of simulating the rainfall teleconnections associated with the main modes of SST variability at short lead time, but model drift appears to hinder this simulation at longer lead times.

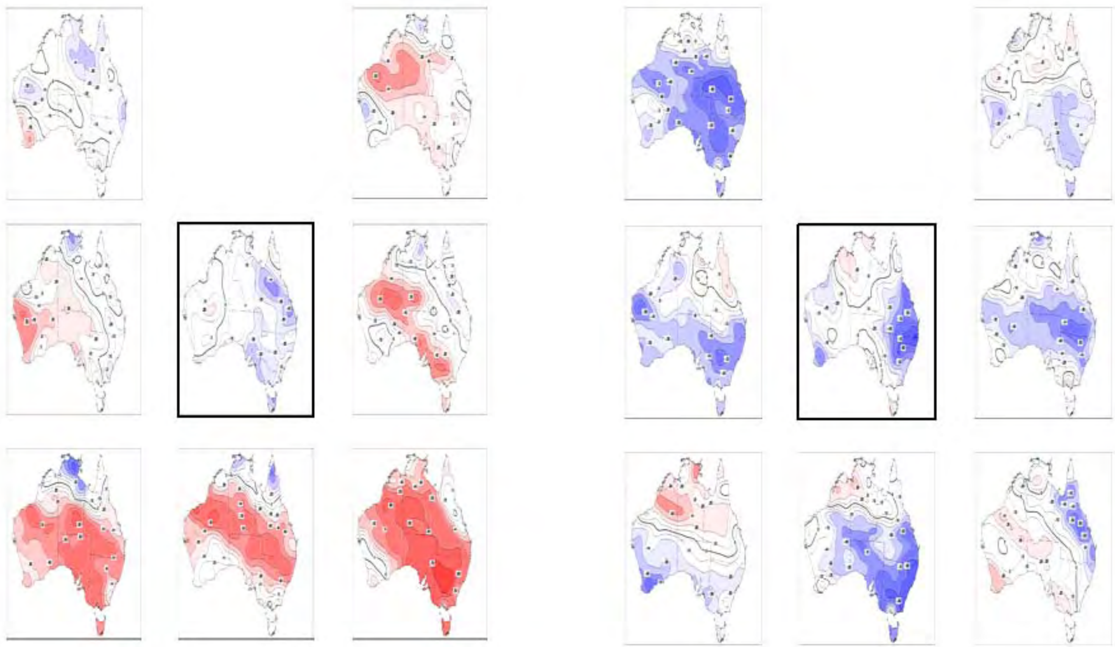

Fig 2. Left panel : Correlation between predicted rainfall and the leading pattern of tropical SST variability (the El Niño mode) for the JJA season from POAMA hindcasts at lead times 0 to 6 months (anticlockwise starting in upper left). Positive (negative) correlations are red (blue). Observed correlation is in center. Right panel: Same but for correlation with the inter-El Niño mode of SST variability:

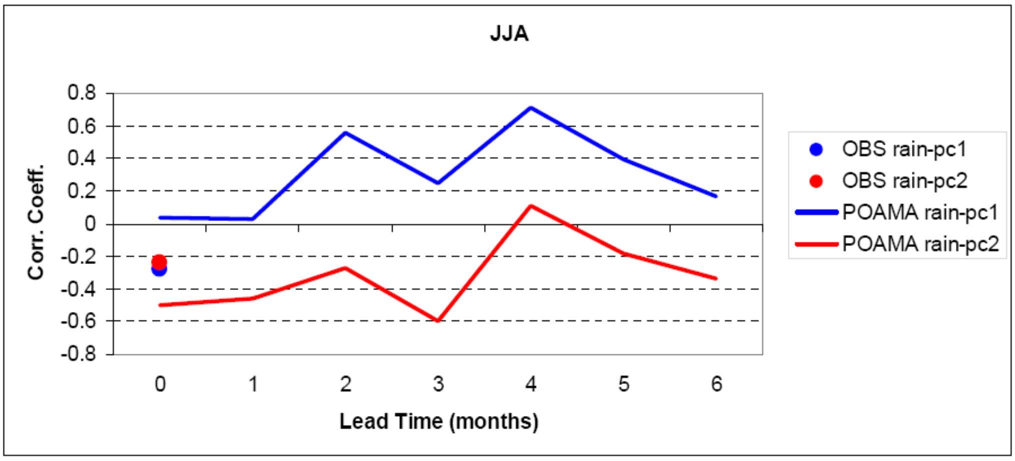

Fig 3. Correlation of SEACI-mean rainfall (landpoints south of 32ºS) with leading patterns of SST variability from observations and from POAMA predictions for JJA season

Conclusions

The current version of POAMA (1.5) has skill in predicting tropical SST variations that are important for Australian climate. This includes not only skill in predicting ENSO, but also extends to the important east-west variation of equatorial Pacific SST of individual ENSO events. Eastern Australian rainfall, especially in winter and spring, is sensitive to these east-west variations of SST; hence, POAMA appears to have important predictive capability beyond simply that of the occurrence of El Niño. POAMA also realistically simulates rainfall teleconnections to Australia driven by ENSO and the inter-ENSO variations of SST at short lead time. However, model drift appears to degrade the realism of these teleconnections at longer lead times. There also appears to be an issue with spin up-, whereby the teleconnection is initially too weak, but then strengthens to realistic magnitudes 1-3 months into the forecast.

These results imply that the model drift needs to be remedied and that initialization needs to be scrutinized. One way to alleviate model drift is to “flux correct” in order to maintain a realistic base state. Flux correction should be considered for future versions of POAMA. Improvements to the ocean initialization system are underway, which might remedy some if the apparent initialization shock (spin up) that has been diagnosed here. The impact of the new ocean initialization will be assessed in the coming year as the system becomes available. However, the best approach in the future will be to develop a truly coupled initialization system, whereby the ocean, land surface, and atmosphere are initialized in unison. Support for such a system should be considered in subsequent programs of SEACI.

In conclusion, this analysis provides optimism for future direct utilization of regional climate forecasts from POAMA. In the meantime, these results provide encouragement for development of hybrid statistical-dynamical forecast schemes (Project 3.2.2), whereby predictable components of the climate from POAMA that are relevant for regional SE Australian climate are exploited by statistical techniques to deliver useful regional predictions.

Acknowledgement

This research was supported by the South East Australian Climate Initiative

Publications/Reports (attached in Appendix)

Hendon, H.H., G. Liu, O. Alves, and G. Wang, 2007a: *Assessment of potential predictability of seasonal climate in SE Australia using the Bureau of Meteorology's dynamical seasonal forecast system.* SEACI Technical Report, Milestone 3.1.3.

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Hendon, H.H., D.W.J. Thompson, and M.C. Wheeler, 2007c: Australian rainfall and temperature variations associated with the Southern Hemisphere Annular Mode. *J. Climate*, **20**, 2452-2467.

Wang, G., and H.H. Hendon, 2007: Sensitivity of Australian rainfall to inter-El Niño variations. *J. Climate*, **20,** 4211-4226.

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Wang, G., and H.H. Hendon, 2007: Sensitivity of Australian rainfall to inter-El Niño variations. *J. Climate*, **20,** 4211-4226.

Project Milestone Reporting Table

To be completed prior to commencing the project				Completed at each Milestone date	
Milestone description[1]	Performance indicators[2]	Completion date[3]	Budget[4] for Milestone ($)	Progress[5]	Recommended changes to workplan[6]

1. Generate ensemble of simulations with atmospheric component of POAMA forced with observed and climo. SST	Integrations completed and archived	September 2006	35K	8 member ensembles for period 1982-2003 generated using 1) global observed SST, 2) tropical Indian Ocean SST, 3) Tropical Pacific SST, and 4) climatological SST Runs have been archived	none
2. Assess simulation and potential predictability of climate variations in SE Australia in ensemble of forced runs and extended run of coupled version of POAMA	Report produced (4 pages)	Jan 2007	20K	Analysis of potential predictability of regional rainfall completed. Report in preparation.	none

3. Assess simulation of modes of climate variability that drive rainfall and temperature in SE Australia in the POAMA hindcasts	Report produced (4-pages)	June 2007	15K	Seasonal variations of the impact of SAM on regional rainfall diagnosed (Hendon et al. 2007). Sensitivity of regional rainfall to inter-El Niño variations of SST diagnosed (Wang and Hendon 2007). Analysis of the relationship between SE Australian rainfall and regional sea surface temperature variations as a function of season using BAM3 simulations commenced. Drift of ENSO mode in POAMA hindcasts has been assessed and calibration to remove drift has been trialled. Sensitivity of SE Australian rainfall to regional SST variations in BAM3 simulations has been assessed. Ability of POAMA to predict higher order modes of SST variability and associated rainfall variations in eastern Australia has been assessed.	