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Focused review of 'advance dynamical seasonal forecast system outputs' for Australian grazing regions

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Abstract

Followings requests from industry to assess ‘’how well are general circulation models (GCMs) performing over recent years” and “when would have been the best occasions to apply GCMs in an operational environment”, a preliminary time series analysis of seasonal climate forecasting skill for broad grazing regions of Australia for the past 6-7 years has been completed. The time series analysis of forecast skill follows an approach that previously conducted by the Bureau of Meteorology on an SOI-based statistical forecasting system for eastern Australia. The analysis of GCM outputs, that incorporated ‘per cent consistent’ hit rates of forecast skill, was performed on data independent of forecast model development and, thus, is referred to as ‘independent verification if real time’. The results suggests generally positive forecast skill results if averaged over the period analysed but with widely varying results if assessed on a year to year or season to season time series basis. Most noticeably is that seasonal forecast skill has only been consistently high over this period if assessed during the onset, duration and cessation of an El Niño or La Niña (ENSO) event but with widely varying results, including very low skill scores, during non-ENSO periods. A further associated comparative analysis also suggests that statistically-based seasonal forecast systems, based on the Southern Oscillation Index (SOI), also possess forecast skill for the regions analysed, especially during ENSO periods, and should not be discarded. It is suggested utilisation of a time-series approach to assessment of seasonal forecast skill be incorporated into any more detailed assessments of seasonal forecast capabilities in the future. The results presented in this study are only preliminary and it is recommended that a more comprehensive time series analysis over a much longer time period than 6-7 years be initiated in order to provide a more comprehensive assessment of the periods of most value in the utilisation of seasonal forecasting, especially of GCMs, in Australia and for Australian rural industry needs.

Executive summary

A number of selected general circulation model forecast systems (chosen on the basis of prior publication outputs and availability of outputs) have been assessed for the period from 2008 until 2013 (approx. 84 forecasts) for broad grazing regions of Australia. The General Circulation Models (GCMs) tested included ECMWF (V4); UKMO (GloSea); POAMA 2.4; and IRI. IRI outputs were finally not included in the complete assessment as output from IRI is only made available in certain periods and not on an ongoing basis for all regions.

In this initial overall comparative assessment, all GCMs performed 'well' in all regions in the years 2010, 2011, and to some extend 2012, although POAMA identified the lower rainfall period in extreme south west Western Australian region ('wheat belt") more skilfully than other models during this otherwise excessively wet period in Australia. **As an overall assessment, the GCMs provided skilful forecasts in approximately three out of the six or seven years studied (depending on model).** ECMWF had the highest overall scores of the GCMs overall across all regions (in regards to assessments of the GCMs), especially in the northwest region and eastern region. POAMA scored quite well in the south-western region in an overall assessment across all years.

Importantly, all GCMs tended to perform 'best' during the core and protracted three-year near-La Niña period of 2010-2012, suggesting, as with an earlier comparative statistical forecasting assessment made by the Bureau of Meteorology (2010), the El Niño/La Niña (ENSO) cycle remains the most important and predictable factor responsible for rainfall variability in Australia. The GCM forecast systems had markedly mixed results in terms of skill scores in other seasons and years with poor skill values in critical periods such as much of 2013.

Results were also conducted for the critical summer pasture production period (October to March) (at least as is relevant for northern Australia) with similar skill-score results obtained for the various GCMs as obtained for all seasons and months tested with obvious forecast capability during ENSO years and seasons but with far less skill in other periods.

The GCMs were also tested in their ability to provide skilful quantitative forecasts at longer lead times – two and three months before forecast validity**.** An interesting aspect is that the GCMs provided similar or even occasionally higher skill results at longer lead times (eg three months before the forecast validity period commenced), especially for north-western and eastern regions and this appears to be a key and valuable attribute of GCM outputs.

POAMA 2.4 outputs analysed also suggest improved skill results at longer lead times, notably for the north-western and eastern zones, but not for the south-western zone**.**

It was also considered useful to assess the performance of one of the better known statistical seasonal forecasting methods, based on the SOI, as an extra cross-assessment of seasonal climate forecasting models in general. Surprisingly, for most regions and periods tested, the SOI-based system produced results comparable to the GCMs at short lead times, with the notable exception of the results for the south-western region.

In a similar result to the previous tests of SOI-based forecasts for New South Wales and Queensland (conducted by the Bureau of Meteorology, 2010) the highest and most skilful periods for use of SOI-based statistical forecasts occurred during La Niña (and El Niño) (ENSO) years, but with mixed results in other periods and years.

This initial study also implies that the contribution of other often important climate drivers (e.g. latitude of the sub-tropical ridge, quasi-biennial oscillation (QBO)) may not yet be captured by the GCMs at this stage of development. Inclusion of these additional climate mechanisms may add considerable value to the usefulness and skill of the GCMs forecasting systems for grazing systems in Australia.

Until these improvements are incorporated, it is suggested judicious use of GCM-based seasonal forecasting systems be applied with application in major grazing systems decision-making preferred for those periods when it is known El Niño or La Niña (ENSO) events are developing or established in the tropical Pacific/Indian Oceans.

It is also recommended that statistical seasonal forecast systems, especially those based on the SOI, be maintained and used as benchmark systems and continue to be applied in management decisions for northern and eastern regions of Australia as GCM continue to be enhanced and improved.

A key role for the GCMs seems to be in provision of advanced lead times, especially during the development and onset of major ENSO events. The GCMs tested also appear to be able to play a key role in forecasting for non-tropical southern/western Australia.

Due to the somewhat unanticipated results obtained above and the industry feedback obtained, this comprehensive analysis was conducted on regions half the size of an initial analysis and in more detail and this is presented in this final report.

It should be note this study was only undertaken, on request, as an initial study over the recent and limited time period of 7 years of forecast output. **A key recommendation arising from this study is that a more detailed assessment for as long as hindcasts may be available and provided is needed to provide a more suitable comprehensive assessment.**

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1 Background

The grazing industry is strongly influenced by the impacts of weather and seasonal climate variation. Frequent major agricultural/animal production losses occur through lack of preparedness for adverse seasons. As such, the success of the industry depends heavily on capitalising on the opportunities and minimising the risks associated with these extreme levels of climate variability. It is suspected that recent and continued advances in ‘dynamical seasonal climate forecasting’ mean that much of this extreme climate variability should be able to be forecast in advance of major impacts, meaning that the grazing industry, particularly meat and livestock industry, clearly has the potential to prepare for the ‘poor seasons’ but also be able to capitalise on the potential opportunities of better seasons ahead when they occur.

However, most, if not all, assessments of climate forecasting research and outputs, to date, have focused on the generalised, successive, three monthly whole-of-season forecasts, rather than analysis of a time series of forecasts issued in real-time. Recent developments in numerical/dynamical weather and climate modelling (known as General Circulation Models – GCMs) (e.g. ECMWF, UKMO, IRI, POAMA (various versions) and similar international modelling systems) offer opportunity, if targeted appropriately, for improving key both tactical and strategic (seasonal or longer) decisions for the meat and livestock industry, especially at longer lead times and periods. Importantly, this will significantly improve understanding of the potential application of more targeted weather/climate forecasts for industry wide supply chain planning and management.

An especially valuable analysis in terms of forecast skill assessment has been conducted by Longford and Hendon (2013) in identifying GCM forecast skill over Australia across all seasons (Fig 1). In this analysis, it was demonstrated that while obvious skill exists in respect to all the models tested, a multi-model approach (multi-model ensemble) was identified as having the most promise of the various models tested. Additionally, while models including POAMA (“P24”) and ECMWF were shown to possess skill in most three month periods and seasons, notably through March to May and through winter and spring periods, markedly less skill was apparent in the models tested for the ‘core’ summer months (December to February) that could be considered critical for pasture growth management through northern and most of eastern Australia. Additionally, the valuable assessment by Longford and Hendon (2013) provided output that was averaged over all forecasts over the entire period but not an assessment of the varying skill over time of forecasts issued in real-time on a year to year basis and which may otherwise provide insight into the contribution of underlying climate mechanisms (such as ENSO) and also value of when best to utilise these types of forecasts.

The Bureau of Meteorology’s National Climate Centre has previously provided useful assessment using a time series approach for the SOI (phase) system (Fig 2). In this, it was shown that the SOI (phases), when used to provide ‘real-time’ forecast were assessed to have high skill in core El Niño and La Niña (ENSO) years over Queensland and New South Wales. This approach also allowed assessment of the value in use of forecasts over a period of time in a ‘real world’ management environment. Such a time series approach may also provide an indication of the value of such forecasts in a ‘real-world’ setting in terms of ‘how well would the models have fared and been of value if I had used them over the past x years’ and which has been requested as the approach required by Meat and Livestock, Australia in this report.

It should be noted that extended (two month) lead time outputs incorporating statistical seasonal climate forecasts have also been demonstrated and tested for grazing regions of Australia (Cobon and Toombs, 2013) which also suggested assessing the value of forecasts at longer lead times as a further assessment of output of GCMs compared with published statistical seasonal forecast systems.

2 Project objectives

The project objectives are to conduct a focused review on the efficacy of the world’s recognised leading general circulation “dynamic” climate models (such as ECMWF; UKMO GloSea; POAMA, IRI) as a time series analysis of forecast skill results for broad regions of Australia, notably those in which extensive grazing activity and industry occurs. Additionally, a check on the comparative capability of ‘well-known’ statistical climate forecasts systems (e.g. SOI – Stone et al, 1996) is an additional aim in order to further assess the efficacy of this new generation of seasonal climate forecast for the major overall grazing regions of Australia.

This project aims to provide a very initial overview of whether progress is being made in seasonal climate forecast development for grazing regions of Australia and whether it is possible to ascertain whether seasonal forecast systems are performing more skilfully in a ‘real-world’ setting of operational or quasi-operational forecast output over successive months, seasons, and years. More importantly a subsequent aim is to assess when and during which type of impact from major climate ‘drivers’ (e.g. ENSO) seasonal forecasting is most valuable. In addition, it was also aimed to assess forecasts at zero to one month lagged periods (that would be available immediately before the forecast period) as well as to assess the efficacy of forecasts with longer lead times, as has been suggested as having value (O. Alves, Bureau of Meteorology, personal communication; A. Arribas, United Kingdom Meteorological Office, personal communication).

3 Methodology

In assessing seasonal climate forecasting, a number of different metrics or skill scores may be applied, with different scores for different applications used in completing this need.

Model verification is taken to indicate skill assessment of independent forecasts, as issued operationally or quasi-operationally (Fawcett and Stone, 2010). This approach has been used to check how a statistical or other type of forecast system is actually performing in a 'real-world' setting over a period of time and this was considered the most suitable approach in this study. This approach can also be used for quality control and accountability purposes (e.g. key performance indicators), but it also can be used to bench-mark a forecast system against other systems, as is also applied here. In addition, in the longer term, this approach may help detect distortions caused by climate change to the underlying statistical relationships between predictor and predictand, assumed in the climate model-building process. (These ideas of validation and verification apply equally to statistical seasonal forecasting and dynamical seasonal forecasting through the use of coupled general circulation models) (Fawcett and Stone, 2010).

In particular, following Fawcett et al (2005) and Fawcett (2008) in their approach to assessing the efficacy of statistical seasonal forecasting, we simply applied the 'per cent consistent' rate as the skill metric used to verify the GCM forecasts. Per cent consistent rates were used to score the GCM forecasts and measures the fraction of times the forecast probabilities swung from climatology (this approach was originally taken from the BoM tercile assessments of rainfall in which the forecast in which the categories are considered to be equally likely but adjusted – as per Fawcett and Stone (2010) – to, in this case, incorporate values above and below the median). Thus, in this assessment per cent consistent rates were assessed on values above and below the median.

Initially an assessment was made over 3 broad regions of Australia and results simplified into a forecast scoring system of between +1 and -1 (where a score of +1 indicated the forecast output of below or above median rainfall matched the observed rainfall as to whether below of above median rainfall occurred and a score of -1 was applied if the forecast was opposite in sign to that observed), developed for ease of use by industry users. However, owing to the further interest by industry in the initial results obtained, a more comprehensive assessment was made to include smaller regions and to fully and more appropriately utilise the system employed by Fawcett and Stone (2010) which employed the full range of per cent consistent values between 0 and 100.

It should be noted that this assessment was based on an initial request for 'a quick analysis' on how the GCMs performed over just the past 5-6 years' and, from this analysis, when GCMs may be more valuable in use in grazing regions for differing seasonal periods. However, given the initial, somewhat interesting results based on a more simple analysis, and in terms of feedback from industry, it was decided to expand this analysis to provide these more detailed assessments that are presented here, despite the fact that the initial analysis was intended as only a brief summary study. It is strongly suggested that this type of more comprehensive time series analysis of operational forecast skill should be extended over a much longer time period (e.g. hindcasts from the past 30 years, if this may be possible) provided such hindcasts - or 'old forecasts' - are made available by the issuing agencies in order to detect the more valuable periods for application of seasonal forecasting in rural industry.

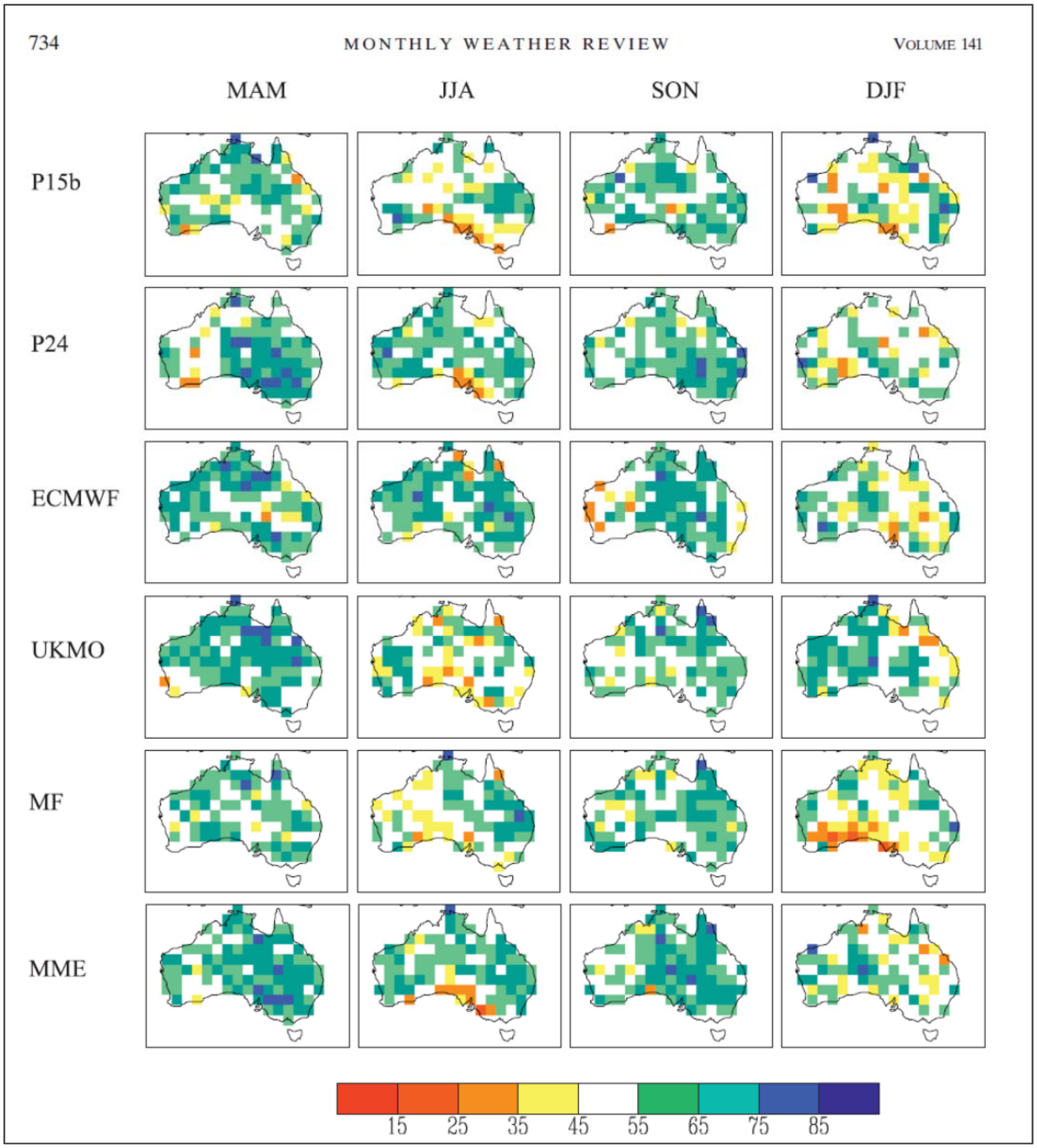

Figure 1. Accuracy score for above/below-median seasonal rainfall for a number of general circulation models: POAMA 1.5, POAMA 2.4, ECMWF, UKMO, and MF models, and the multimodel ensemble using P24, ECMWF, UKMO, and MF models (MME; 54 members total). The authors note the lead time is one month and an accuracy score greater than 50%, as indicated by green and blue shades, is considered skilful (from Langford and Hendon, 2013). Note the issue of reduced skill apparent for eastern Australia in the key summer months of December/January/February (DJF) in most models.

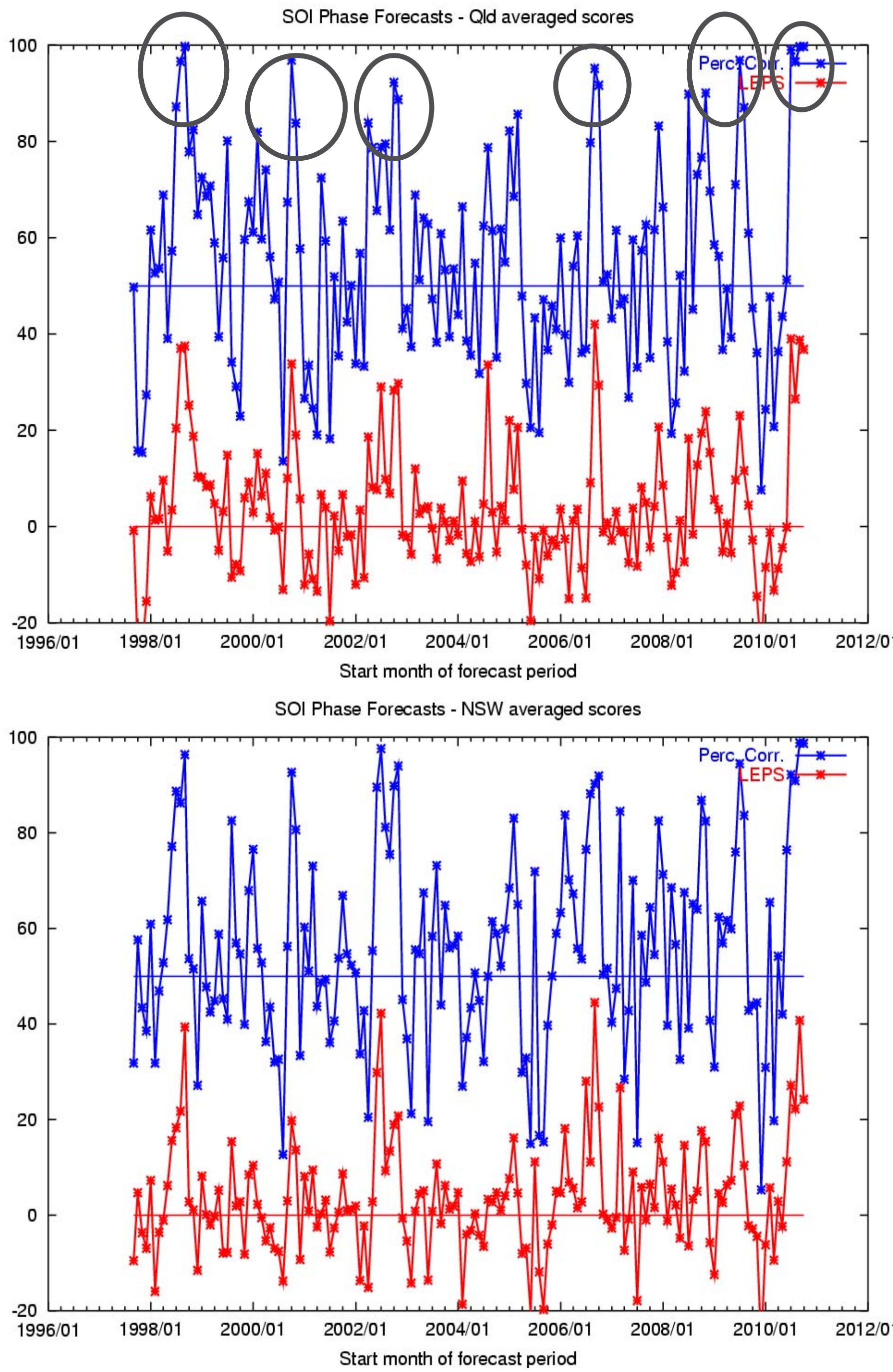

Figure 2. Time series of a seasonal climate forecast system skill for Queensland (top) and New South Wales (lower) for the SOI phase system from 1996 to 2011. Both 'per cent correct' (blue) of grid squares where the forecast matched the observed rainfall as to whether above or below the median and associated linear error in probability space (red) skill scores. Highest skill scores – approaching 100% in a number of cases – in this statistical forecasting system mostly occur during major El Niño and La Niña events and periods – ENSO periods: circled (analysis courtesy Bureau of Meteorology).

4 Results

In application of a similar approach to that applied to assessment of the statistical forecasting systems (i.e. following the approach applied in Figure 2) the following results are provided here:

- **Queensland:** all GCMs tested provided modest to high skill (at one month lead time) for the period 2010-2011 (inclusive), and to some extent, 2011/12 (**Figure 3**). There is also potential for three month lagged forecasts for this region (Figure 4) with high skill advanced forecast skill suggested for the ‘wet’ - La Niña period - of 2010-2011.

- **New South Wales/Victoria zone**, all GCMs tested provided modest to good skill (at one month lead time – **Figure 5**) for the period 2010-2011. However, for other periods, the results were decidedly mixed. **Figure 6.** Provides information for assessment of the forecast skill through the New South Wales/Victoria (NSWVIC) region as a month-by-month analysis utilising 3 month lagged hindcasts from POAMA, UKMO, and ECMWF model outputs since 2008 and suggests high skill between the autumn period of 2010 and 2011 but also in other periods such through 2011/12.

- **North-western zone**, the GCMs tested (at one month lead time) performed especially skilfully (well) during the La Niña period between autumn 2010 and autumn 2011 and similarly for summer 2013, but comparatively poorly in the other periods/years (eg: 2008, 2009, and the remainder of 2013) (**Figure 7**). Similarly, with three-month lagged GCM outputs the GCMs tested provided skilful forecasts for the critical La Niña period between autumn 2010 and autumn 2011 but also for the summer of 2011/12 – and potential for the most recent period of late 2013 (**Figure 8**).

- For the **central north region** (Northern Territory/Barkly Tablelands) utilisation of one month lagged hindcasts from POAMA, UKMO, and ECMWF model outputs since 2008 suggest especially useful and high forecast skill for the key autumn 2010 to autumn 2011 period but with (widely) varying results for other seasons (**Figure 9**). Apparently equivalent results have been obtained for this region utilising three-month lagged forecast outputs (**Figure 10**).

- For **the southwest region** (incorporating much of southwest Western Australia) quite highly varying results have been obtained over this period analysed with some periods displaying high skill but often immediately displaying low skill. For example, utilising one-month lagged forecasts, during the strong La Niña period of 2010/2011 some three month forecast periods were associated with high skill forecasts but adjacent periods (especially winter) were associated with low skill forecasts (**Figure 11**). Similarly, with

three-month lagged forecasts there were quite varying periods of high and low skill but perhaps notably ECMWF appeared to provide more consistently high skill during the autumn 2010 to autumn 2011 strong La Niña period (**Figure 12**).

- For the **central-south region** utilising one **month lag hindcasts** from POAMA, UKMO, and ECMWF model outputs since 2008 the results suggest widely varying skill over this period but with noticeably high skill during the strong La Niña period of autumn 2010 to autumn 2011 and, again, to some extent during 2012 (**Figure 13**). Similarly and notably, three month lagged forecast outputs performed as well, especially during the 2010/2011 La Niña period but also during the summer period of 2012/2013 (**Figure 14**).

- **Assessment of comparative time series skill of POAMA and an SOI-based seasonal forecasting system** is provided in Figure 15 for the Queensland region**.** In an interesting outcome it is suggested both types of seasonal forecast system appear to perform equally well overall but with widely varying results depending on the existence or otherwise of El Niño or La Niña events. For some periods (e.g. 2008 and continuing the similar type of analyses and output conducted in Figure 2) the SOI-based system provided high skill scores while in other periods (2012 and the latter part of 2013) the POAMA forecast system provided high skill scores. Note that this assessment is only for zero (SOI-based approach) or one month lag (POAMA system) and not for more extended lagged periods such as three month lagged periods as the statistical SOI-phase based approach was designed for zero lag and not extended lagged periods – for the longer lead/lagged periods the GCMs analysed appear to provide a considerable advantage over the statistical systems analysed here.

- For **NSW/Victoria comparison** of the statistically SOI-based system with POAMA suggests similar results to Queensland with the SOI-based system performing well during some periods (e.g. 2009) but POAMA performing considerably well during other periods (e.g. 2012) (**Figure 16**).

- For the **central-south region (Figure 17) comparison** of the statistically SOI-based systems with POAMA suggests periods with an SOI-based approach performed well (e.g. 2008/2009) and other periods when the POAMA system performed well (e.g. 2012). Both systems provided very similar strong results during the strong La Niña period between autumn 2010 and autumn 2011.

- For the **south-west region (Figure 18)** seasonal forecast results associated with both POAMA and an SOI-based system suggest widely varying results with some periods of noticeably high skill and other periods with noticeably low skill. Additionally each forecast system could, for the same period, produce exactly opposite skill results both positively and negatively.

- The **central north region** (**Figure 19**) (incorporating the Northern Territory and Barkly Tablelands) provided varying results for the POAMA forecast system and an SOI-based system. The SOI-based system suggests it possessed high skill through 2008, 2009, and 2010/11 but mixed results after that. The POAMA system provided varying skill periods but noticeably well during 2010/11. Both systems provided poor skill values during much of 2013.

- **Figure 20** provides time series of skill scores for the **north-western region** and suggests value in use of the SOI-based approach in this region especially between 2008 and autumn of 2012. POAMA provided varying skill results for this region over this period.

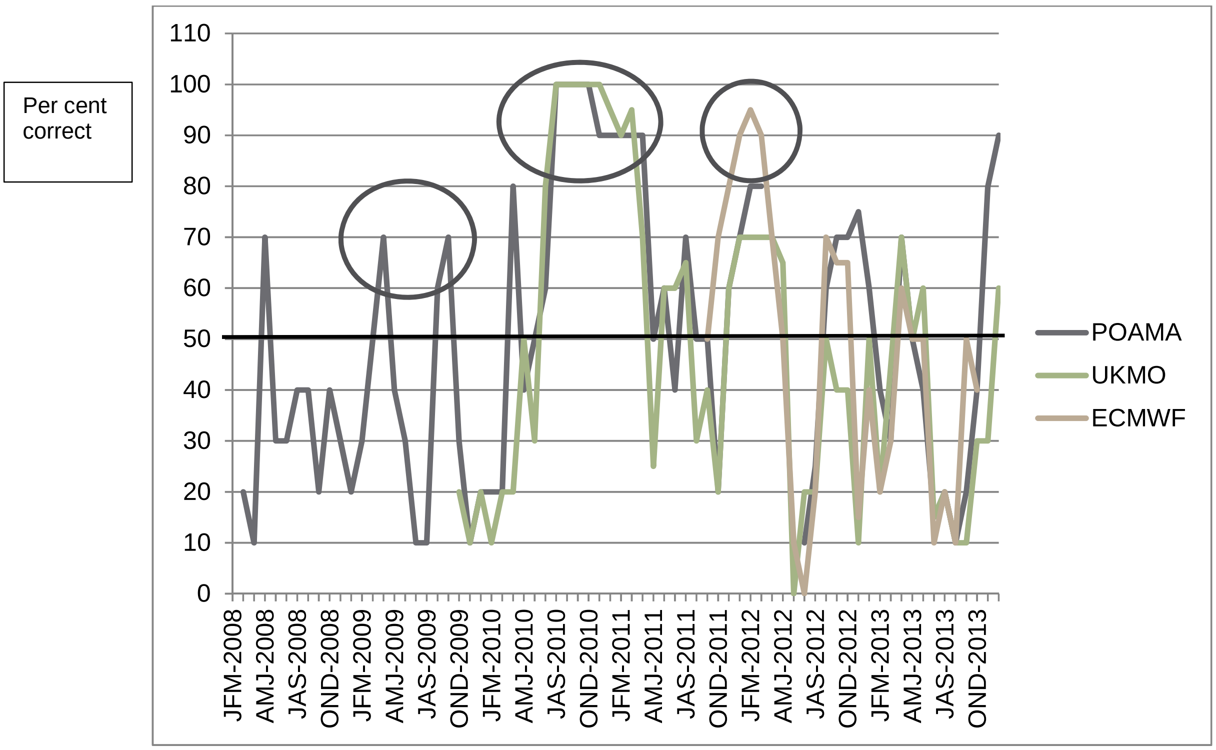

Figure 3. Queensland region: month-by-month analysis utilising 1 month lag hindcasts from POAMA, UKMO, and ECMWF model outputs since 2008 - ENSO periods are circled (as further hindcasts are obtained these results will be updated).

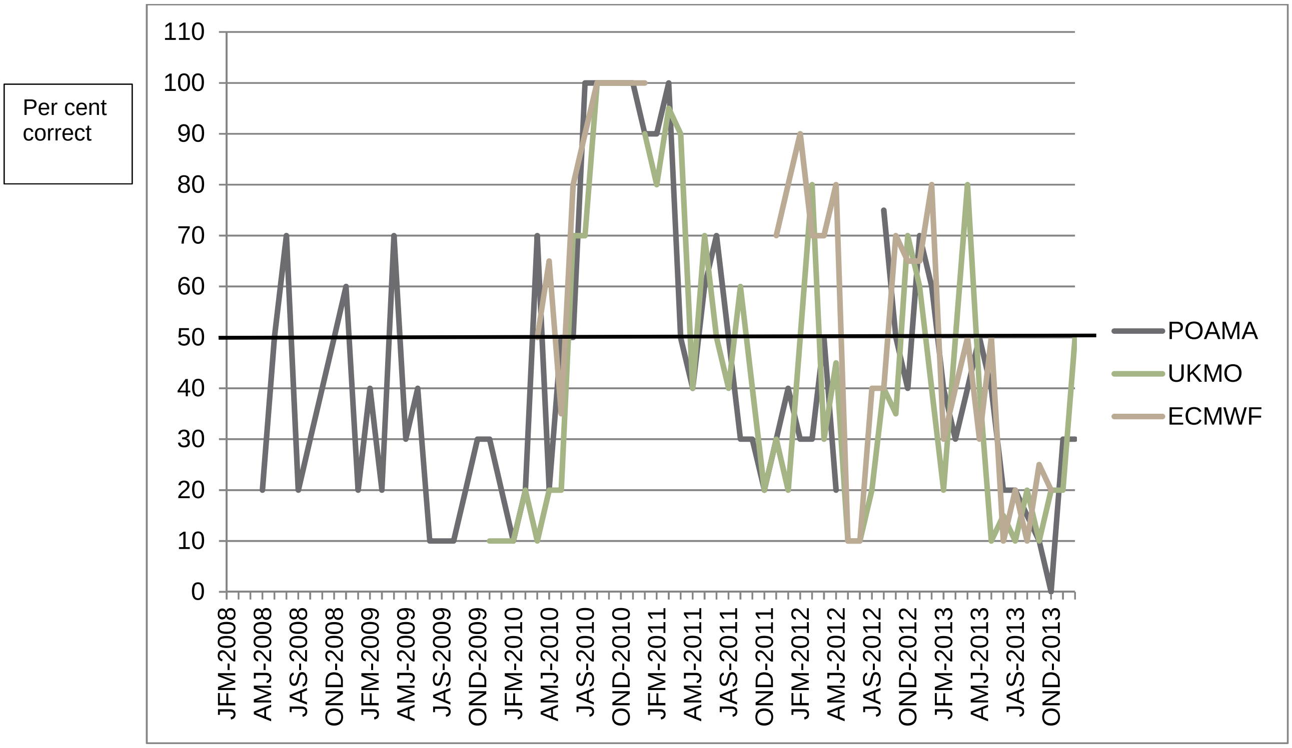

Figure 4. Queensland region month-by-month analysis utilising **3 month lag hindcasts** from POAMA, UKMO, and ECMWF model outputs since 2008.

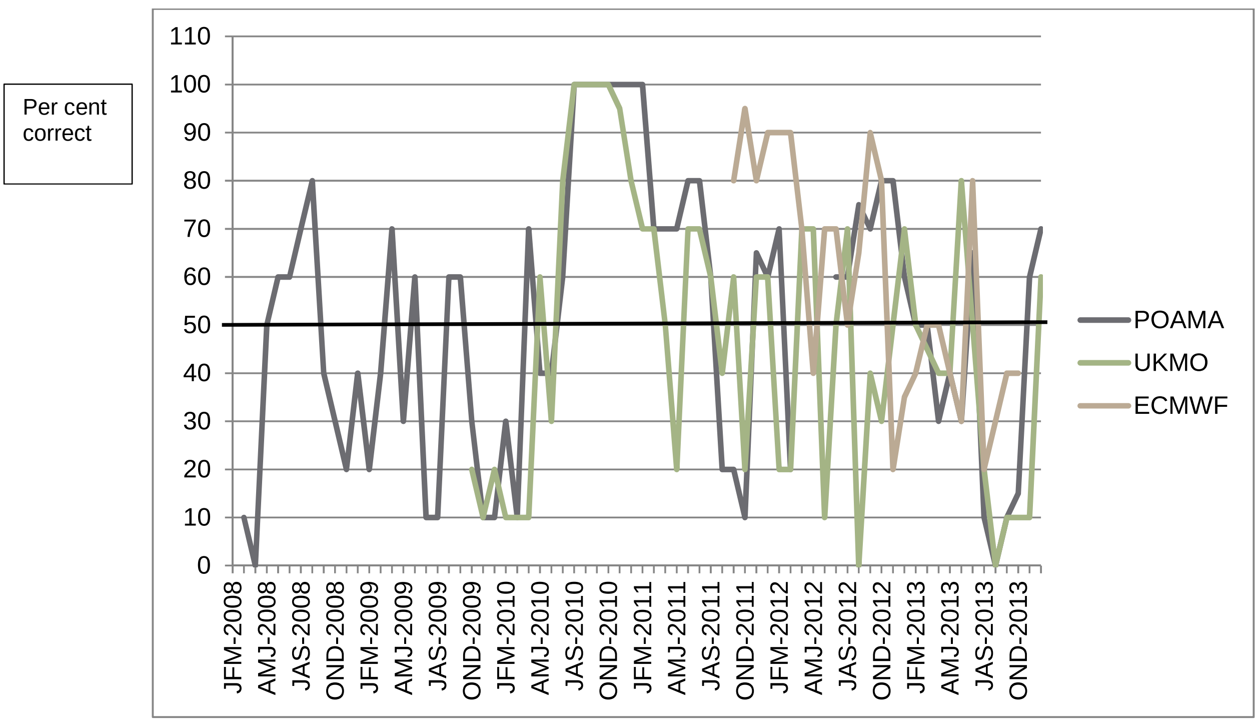

Figure 5. New South Wales/Victoria (NSWVIC) region month-by-month analysis **utilising 1 month lag** hindcasts from POAMA, UKMO, and ECMWF model outputs, since 2008 (as further hindcasts are obtained these results will be updated).

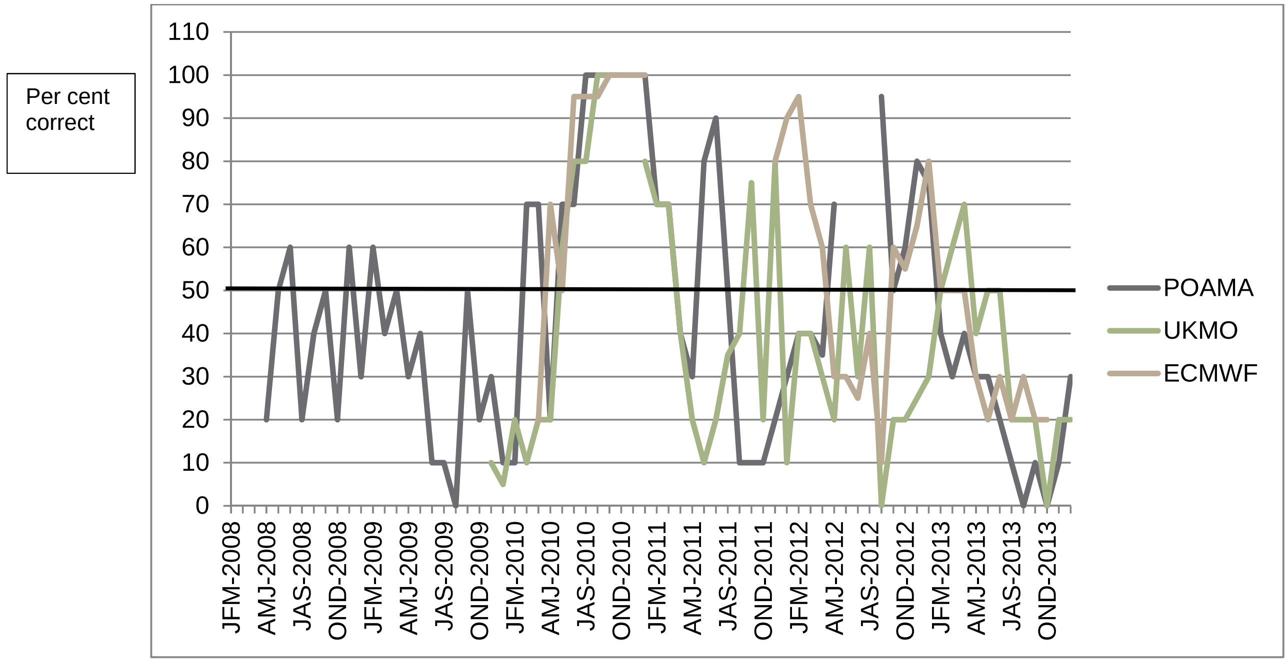

Figure 6. New South Wales/Victoria (NSWVIC) region month-by-month analysis **utilising 3 month lag** hindcasts from POAMA, UKMO, and ECMWF model outputs since 2008 (as further hindcasts are obtained these results will be updated).

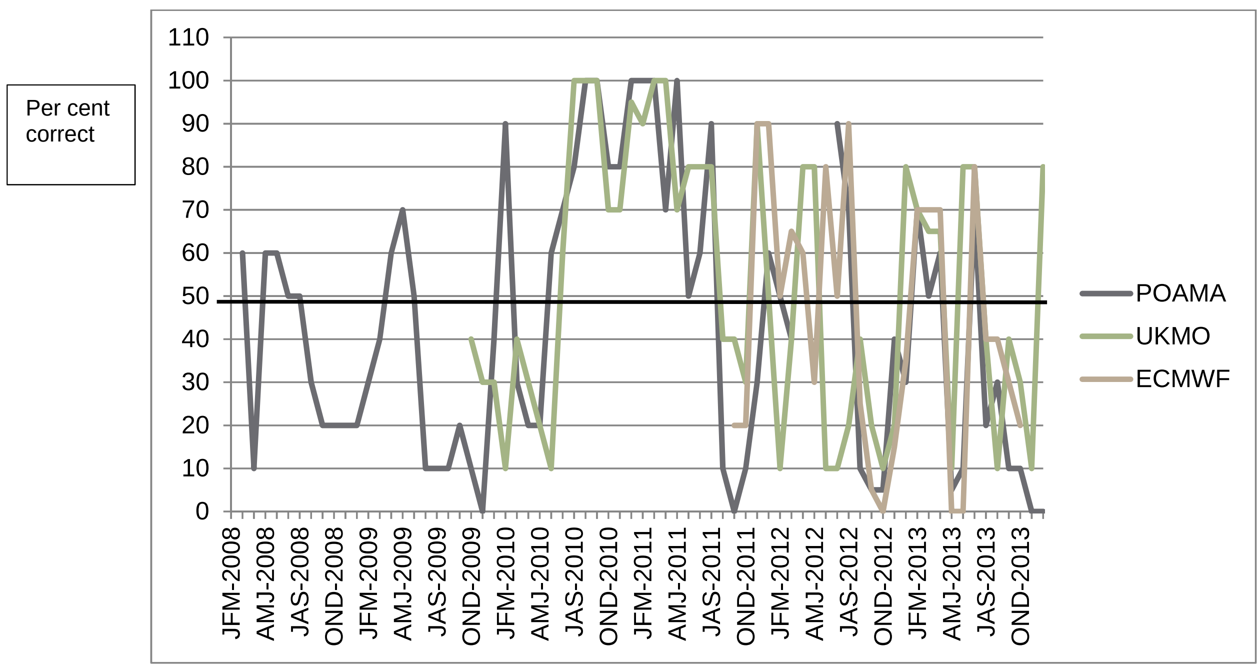

Figure 7. Northwest region month-by-month analysis utilising 1 month lag hindcasts from POAMA,

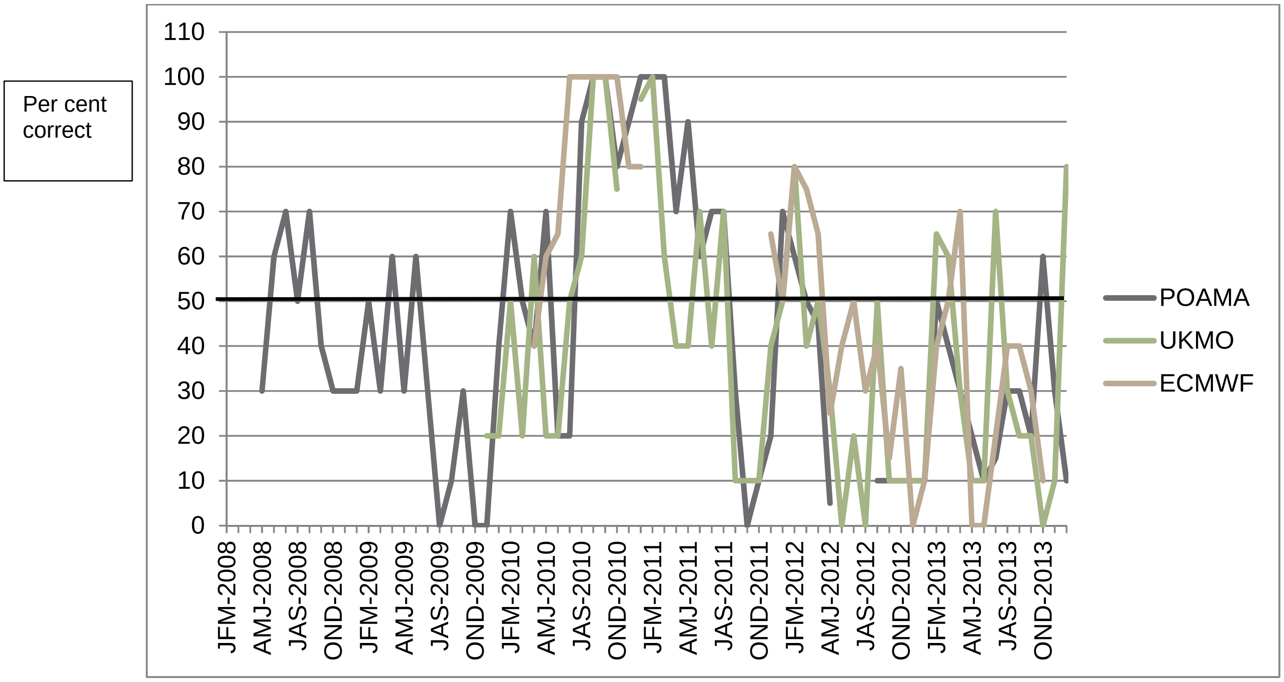

Figure 8. Northwest region month-by-month analysis **utilising 3 month lag hindcasts** from POAMA, UKMO, and ECMWF model outputs since 2008 (as further hindcasts are obtained these results will be updated).

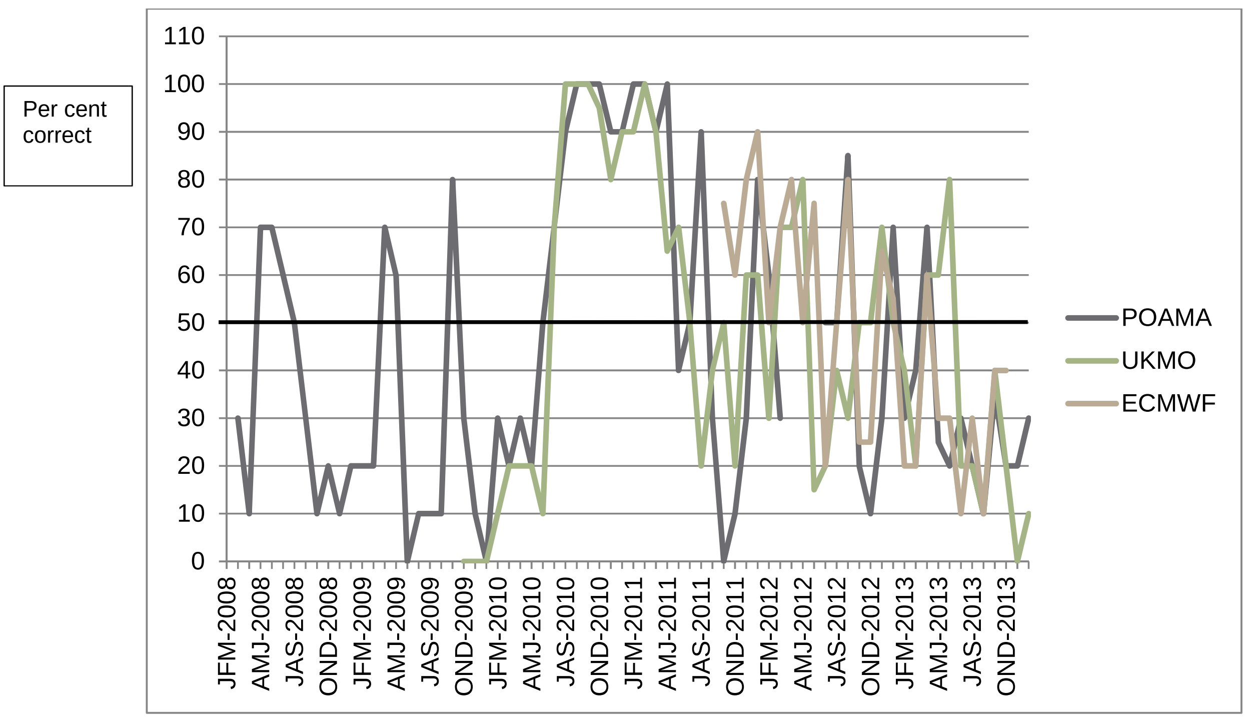

Figure 9. Central north region (Northern Territory/Barkly Tablelands**) utilising 1 month lag hindcasts** from POAMA, UKMO, and ECMWF model outputs since 2008.

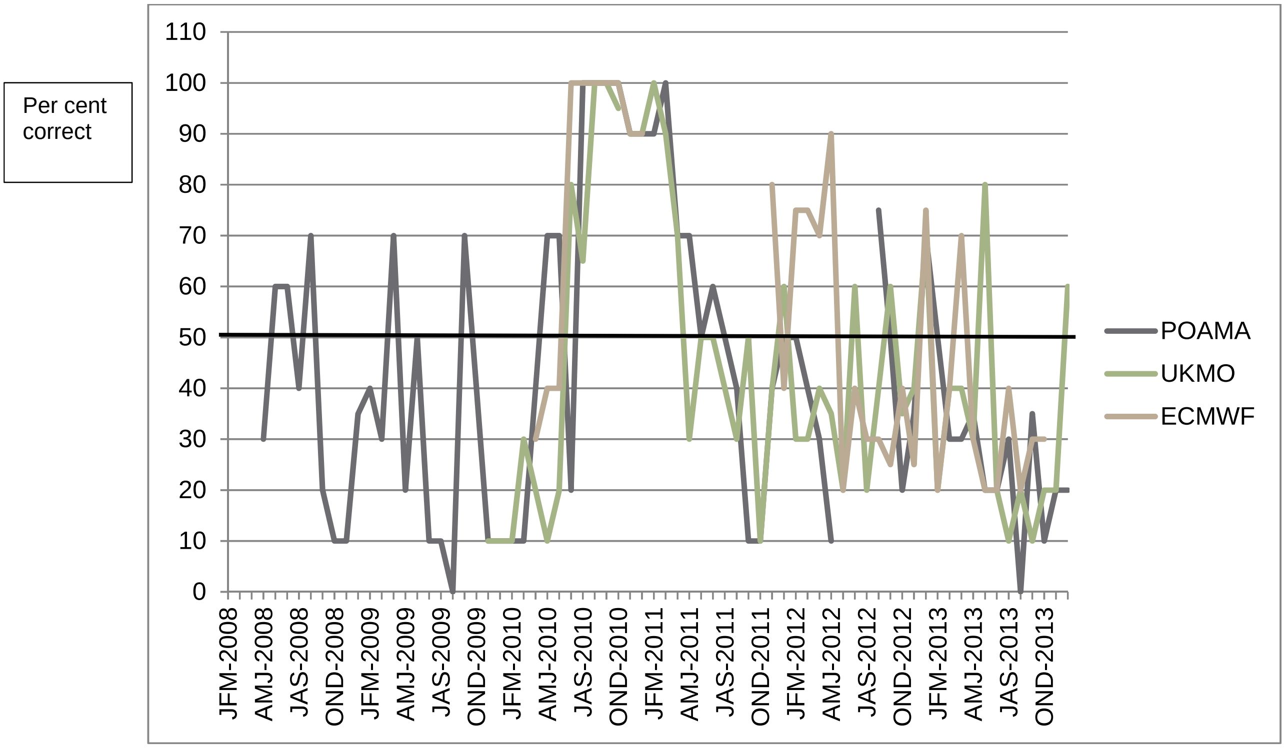

Figure 10. Central north region (Northern Territory/Barkly Tablelands) **utilising 3 month lag hindcasts** from POAMA, UKMO, and ECMWF model outputs since 2008.

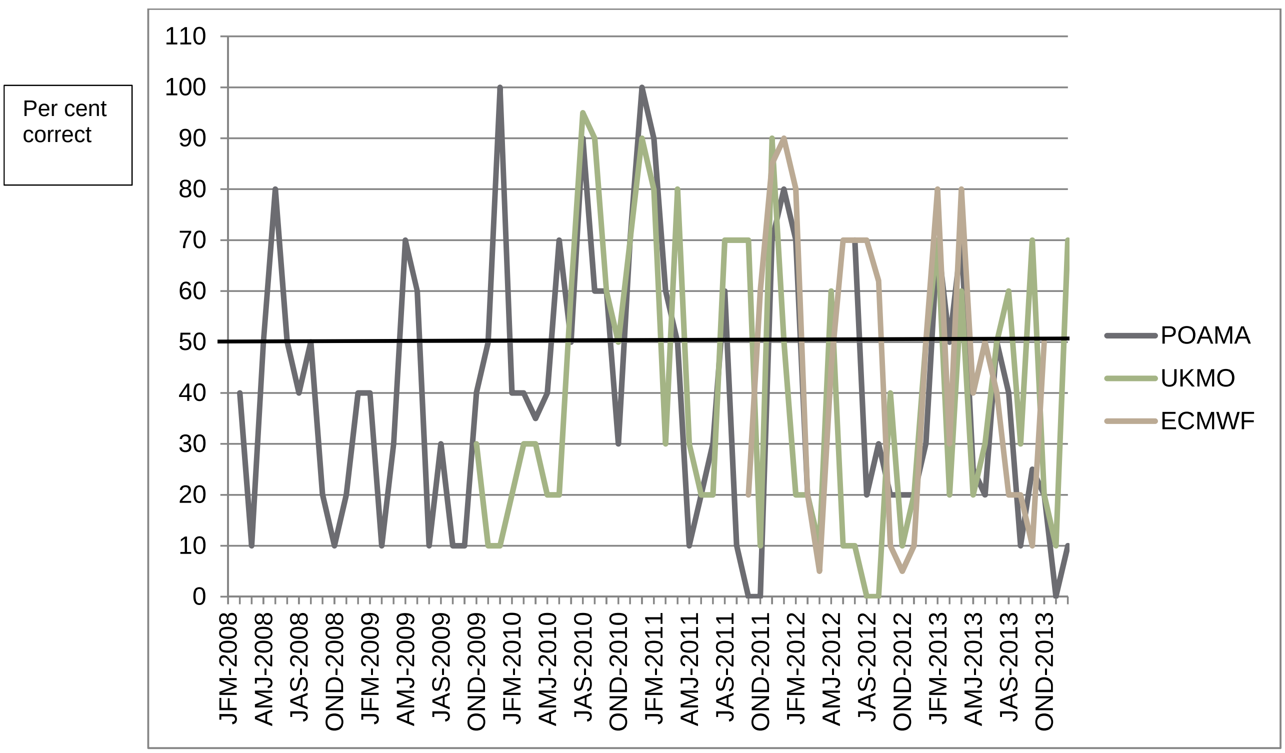

Figure 11. Southwest region **utilising 1 month lag hindcasts** from POAMA, UKMO, and ECMWF model outputs since 2008 (as further hindcasts are obtained these results will be updated).

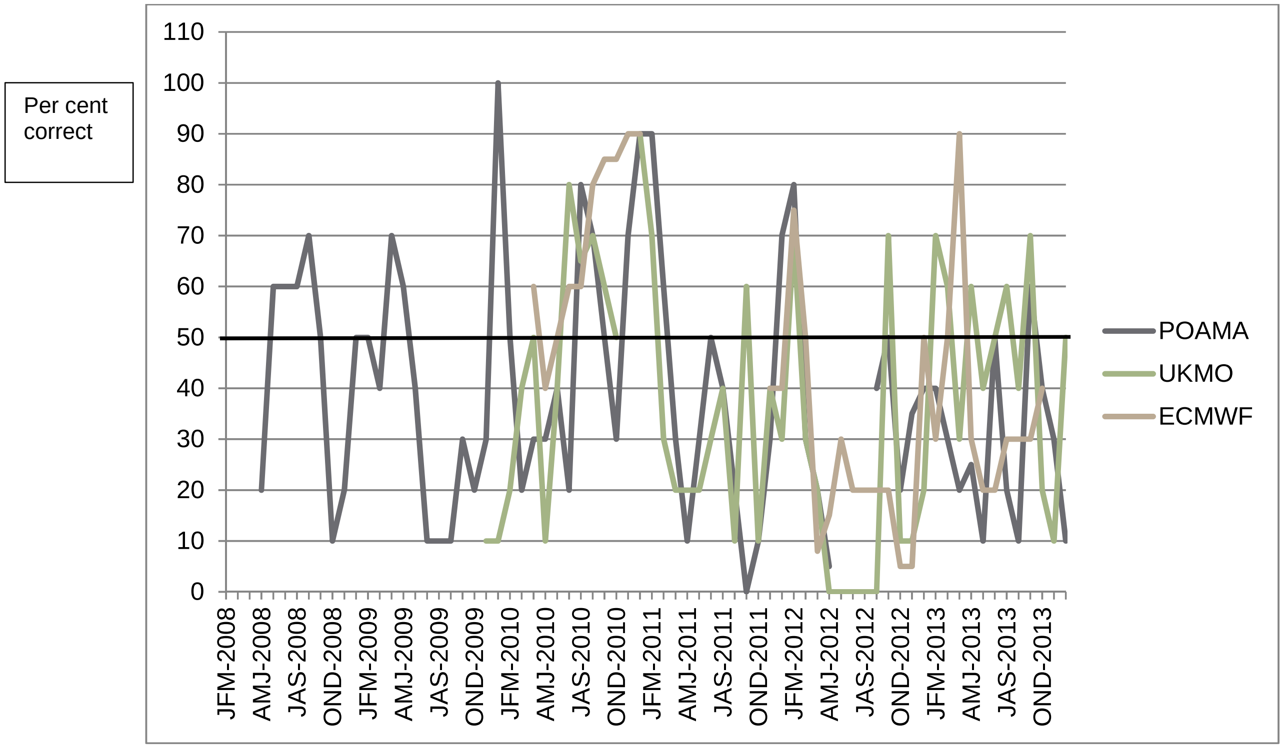

Figure 12. Southwest region **utilising 3 month lag hindcasts** from POAMA, UKMO, and ECMWF model outputs since 2008 (as further hindcasts are obtained these results will be updated).

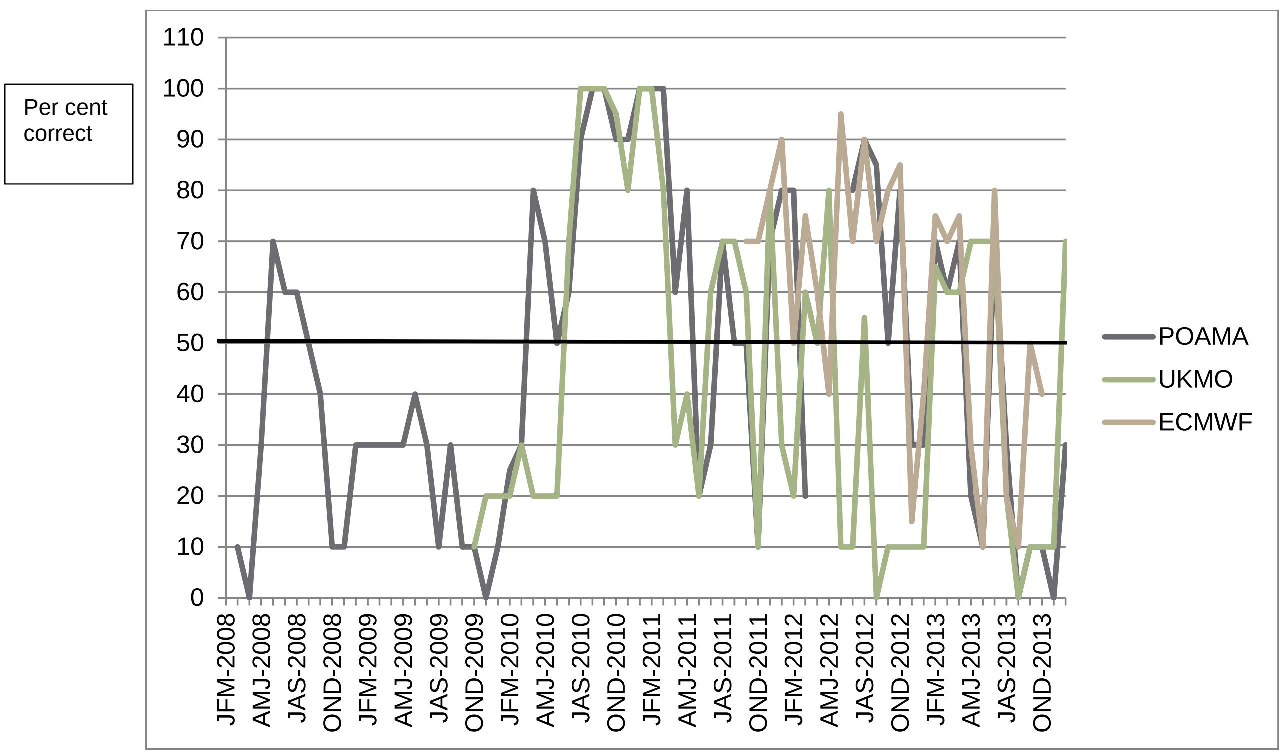

Figure 13. Central-south region utilising **1 month lag hindcasts** from POAMA, UKMO, and ECMWF model outputs since 2008 (as further hindcasts are obtained these results will be updated).

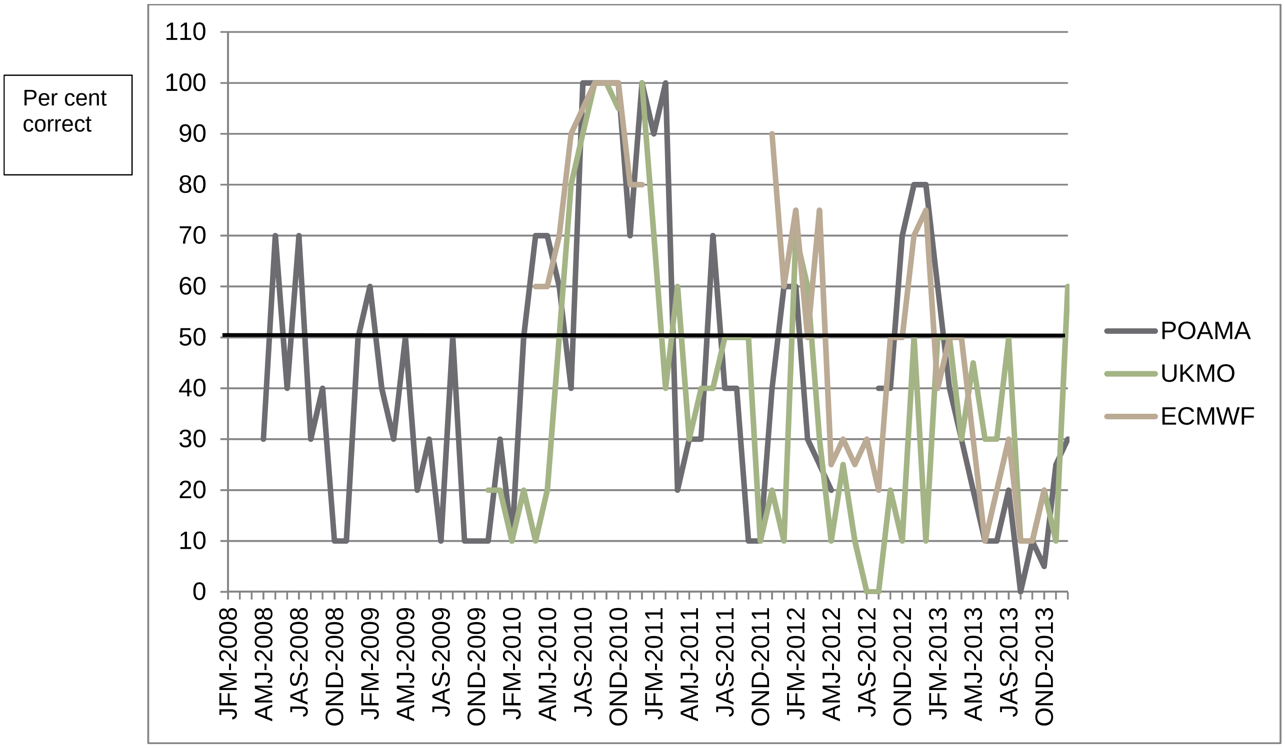

Figure 14. Central-south region **utilising 3 month lag hindcasts** from POAMA, UKMO, and ECMWF model outputs since 2008 (as further hindcasts are obtained these results will be updated).

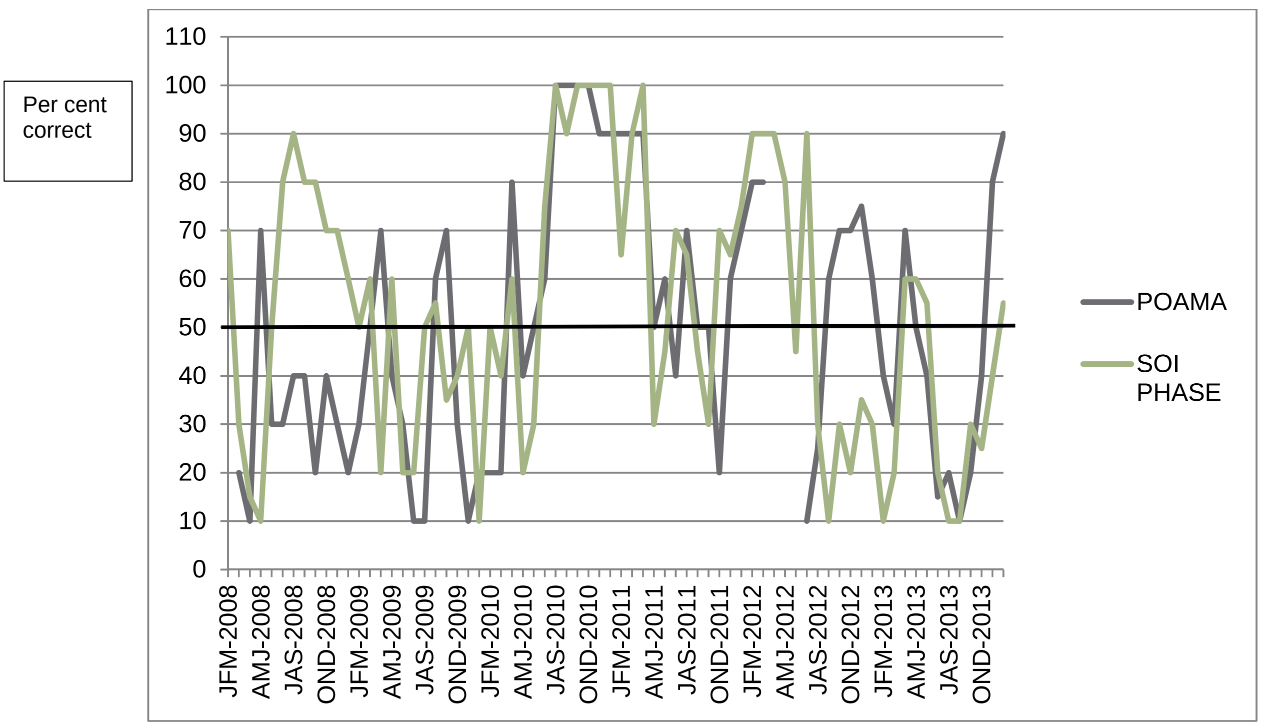

Figure 15. **Queensland region POAMA hindcast values** and an SOI-based statistical approach values (one-month lag).

Per cent correct

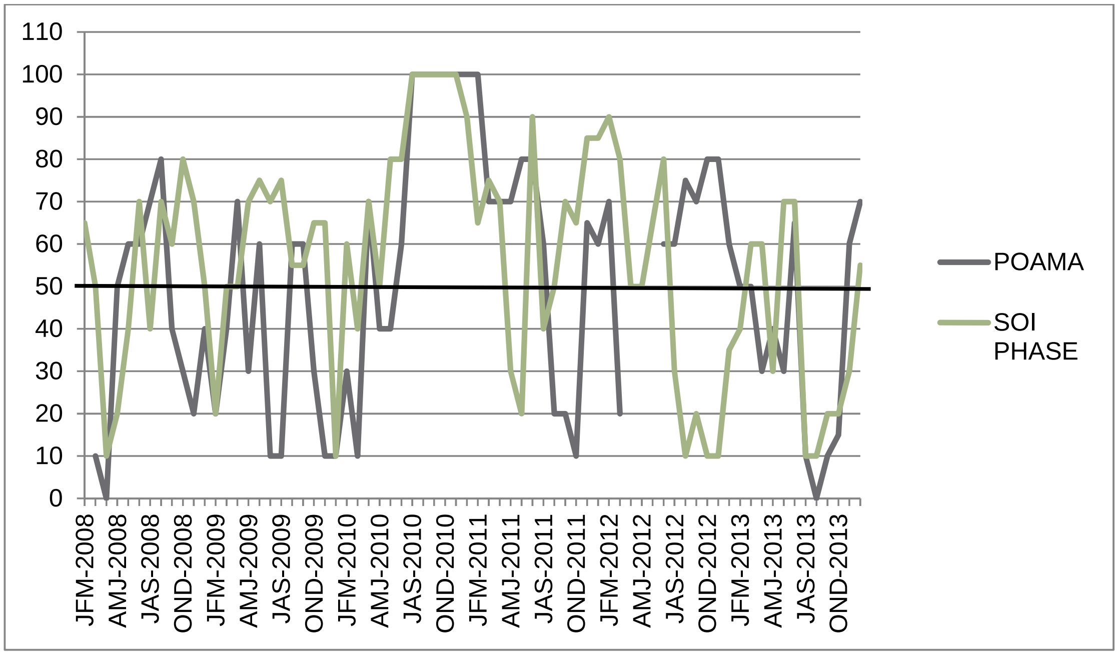

Figure 16. **NSW/Vic region** utilising POAMA hindcast values and an SOI-based statistical approach values (one-month lag).

Per cent correct

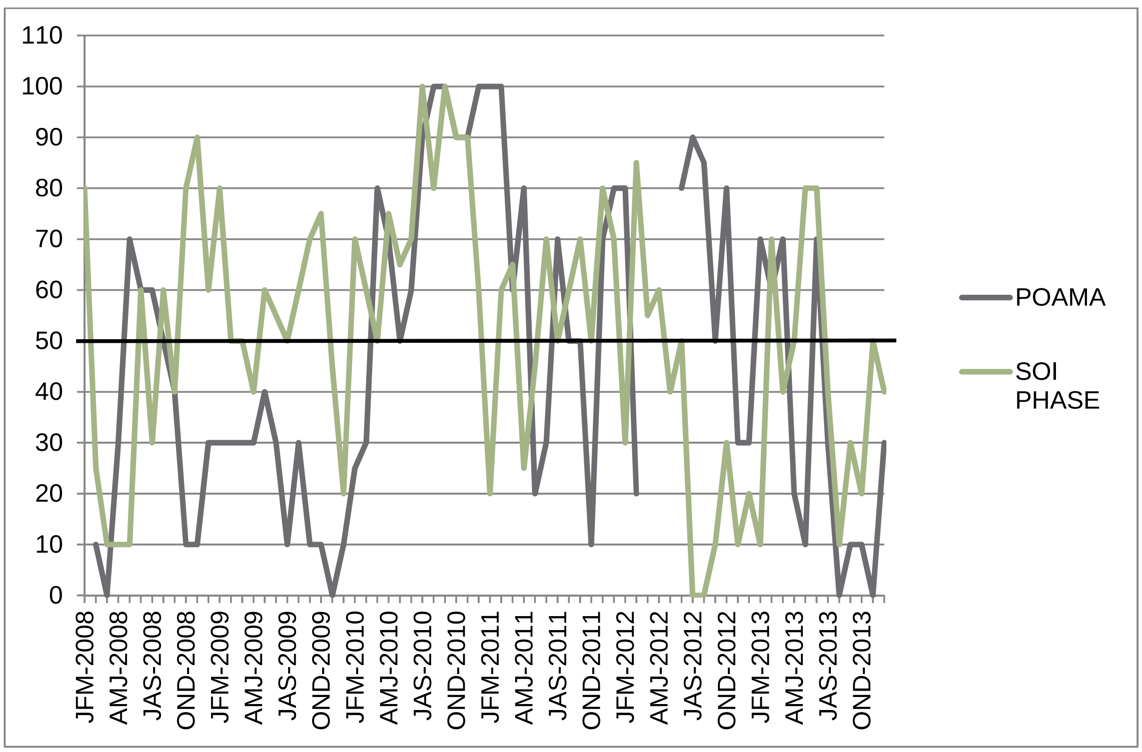

Figure 17. **Central south region** utilising POAMA hindcast values and an SOI-based statistical approach values (one-month lag).

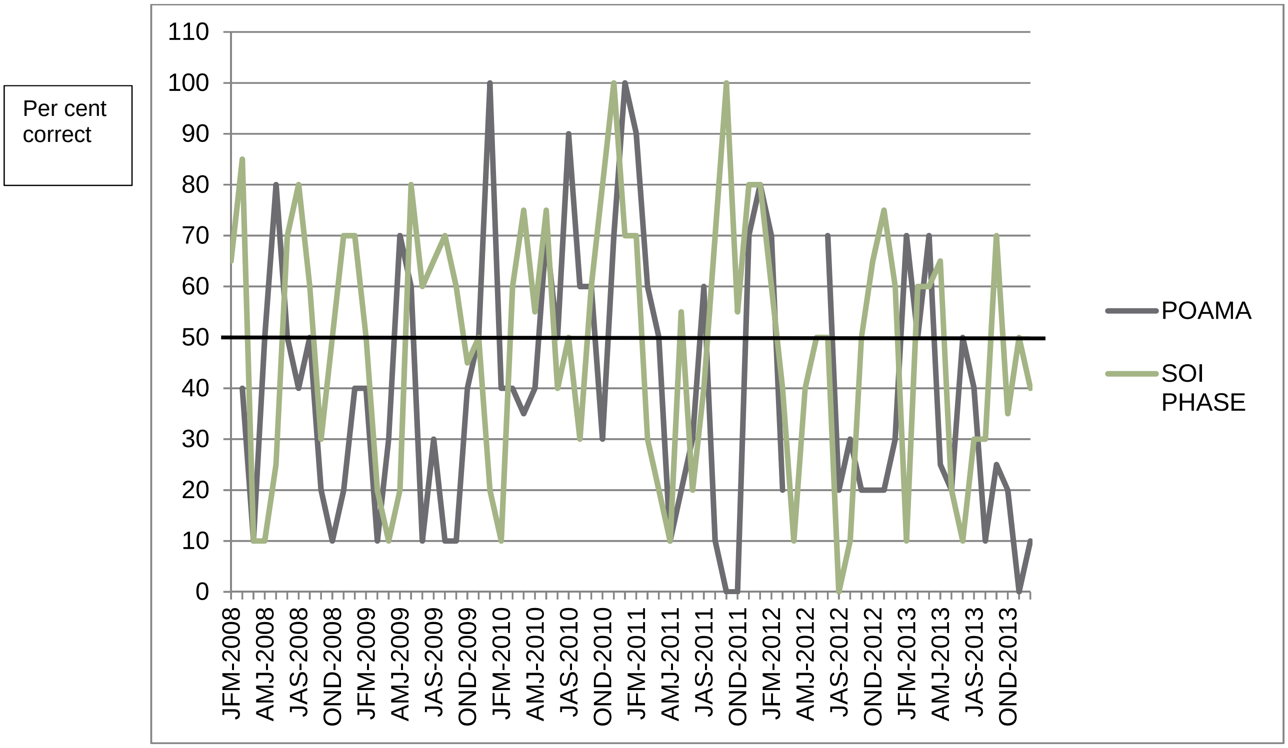

Figure 18. **South-west region** utilising POAMA hindcast values and an SOI-based statistical approach values (one-month lag).

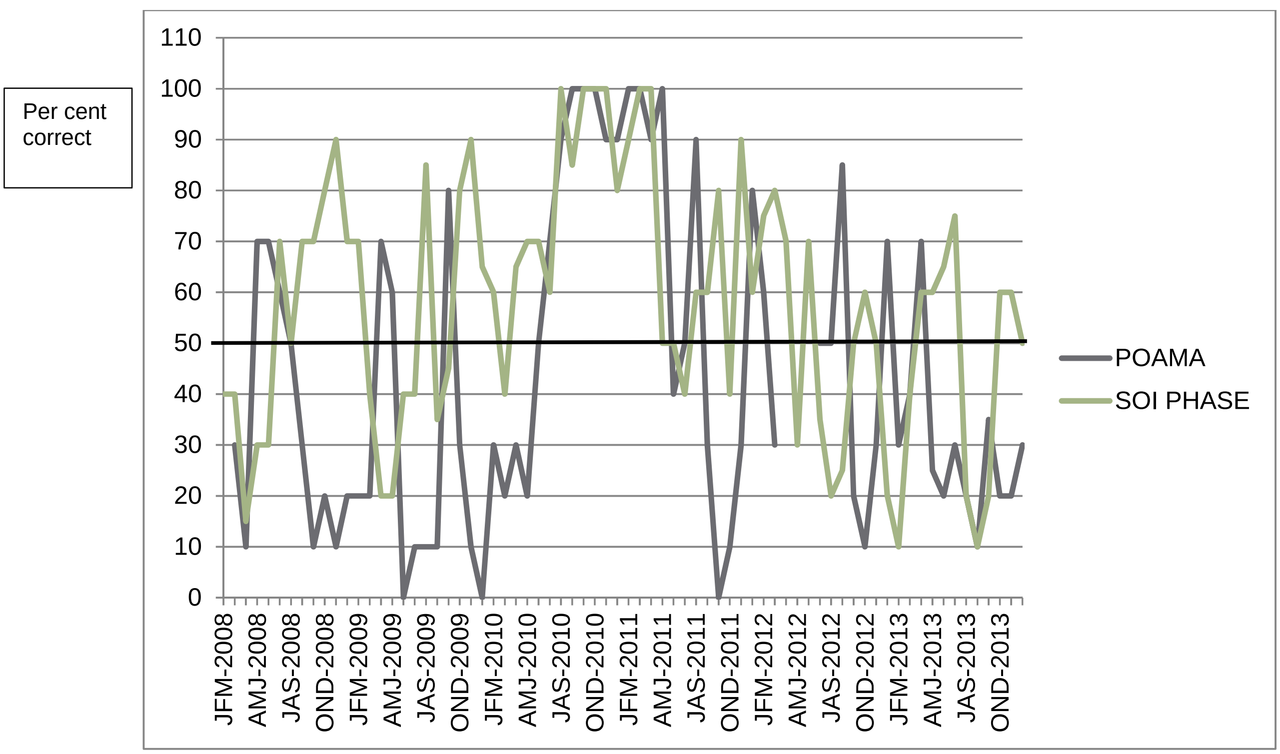

Figure 19. **Central-north region** utilising POAMA hindcast values and an SOI-based statistical approach values (one-month lag).

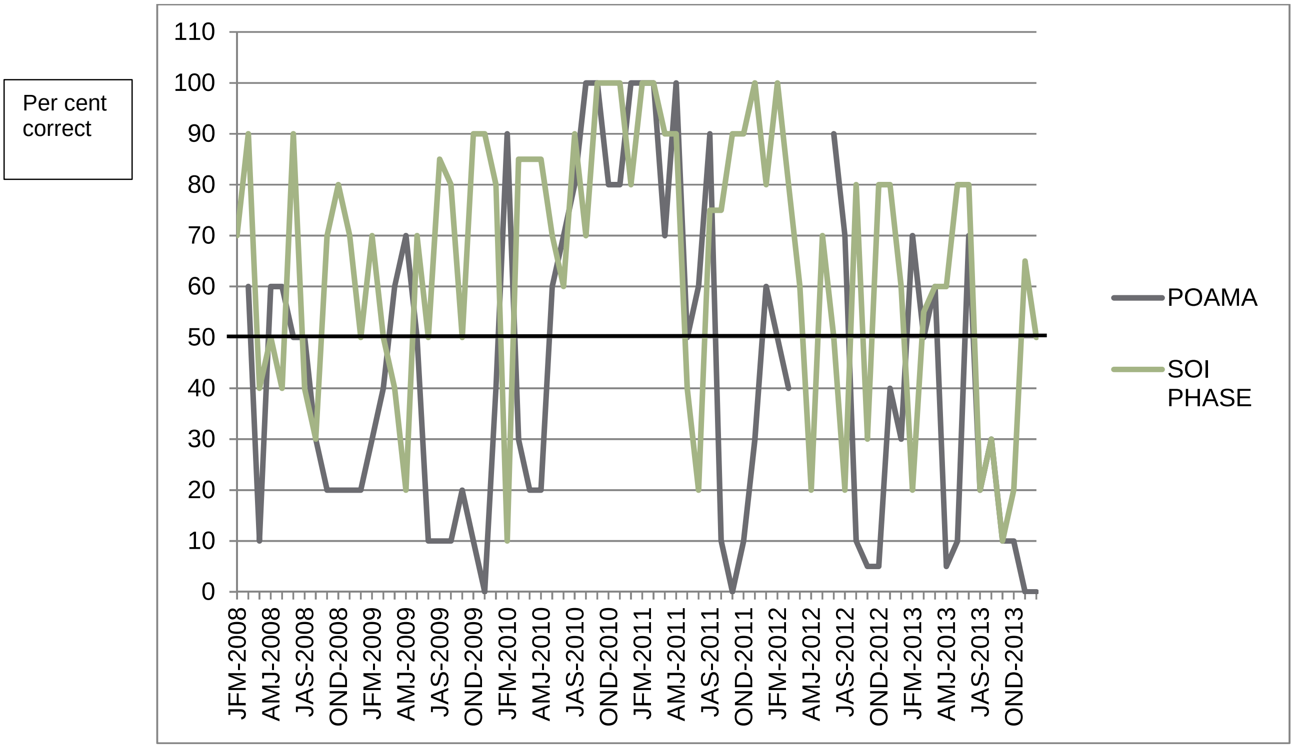

Figure 20. **North-west region** utilising POAMA hindcast values and an SOI-based statistical approach values (one-month lag).

5 Discussion / Conclusions

It is emphasised that the analysis provided in this report is based only on a relatively short period of forecast output of approximately 6-7 years (up to 84 forecasts) (as requested by Meat and Livestock Australia - MLA) and that some GCM outputs for some earlier periods have yet to be received from the issuing agency at the time of compiling this report.

It is strongly suggested a more lengthy analysis be conducted for as long a period as hindcasts ('old forecasts') can be provided - for example up to 30 years - in order to create a more detailed, comprehensive, and valuable assessment. Nevertheless, it is suggested the conducting of this time series of skill results (for the recent period of interest as requested by MLA) provides added and valuable insights into the performance of seasonal climate forecasting systems in terms of their most valuable periods of skill, with implications for the most valuable periods of use of such forecasts by industry decision making.

In this study, a number of selected general circulation model forecast systems have been assessed for the period from 2008 until 2013 (approx. 84 forecasts) for very broad grazing regions of Australia. In this overall comparative assessment, all GCMs performed 'reasonably well' in most regions in the years 2010, 2011 and to some extent, 2012. POAMA identified the lower rainfall period in extreme south west Western Australian region ('wheat belt") more skilfully than other models during this otherwise excessively wet period of 2010 in Australia. Overall, the GCMs provided skilful forecasts in about three out of the six or seven years studied (depending on model). POAMA scored quite well in the south-western region in an overall assessment across all years.

Notably, all GCMs tended to perform well in terms of per cent consistent rates during the core and protracted three-year near-La Niña period of 2010-2011-2012 (suggesting the El Niño/La Niña (ENSO) cycle remains the most important and predictable factor responsible for rainfall variability in Australia). However the GCM forecast systems had markedly mixed results in other seasons and years.

GCMs such as ECMWF provided similar or even occasionally higher skill results at longer lead times (e.g. three months before the forecast validity period commenced) as compared to short lead times of zero or one month, especially for north-western and eastern regions. POAMA 2.4 outputs analysed also suggest improved skill results at longer lead times, notably for the north-western and eastern zones (but not for the south-western zone). It is considered this is an important result and suggests further value assessment for industry application.

Perhaps surprisingly, for the north-western and eastern regions for the periods tested, an SOI-based statistical forecast system produced results comparable to the GCMs However, this was not the case with the south-western region. Additionally, generally (with the exception of the work for regions analysed by Cobon and Toombs (2013), SOI-based systems do not generally provide advanced or long lead time forecast capability out to three months or longer, which appears to be an inherent quality of the GCMs in application to industry use in Australia.

Although independently tested each of the GCMs provide remarkably similar forecast results for each region and for each individual three month period – the figures demonstrate each GCM tracking comparably. (Each GCM was independently tested for each time series result and then the final values combined into the graphical presentations).

There have been easily recognisable periods when the GCMs performed exceptionally well in Australia – e.g. the period 2010-2011, inclusive. **It appears that, as is the case with statistically-based forecast systems and following the results provided by the Bureau of Meteorology in a previous study (Figure 2), ENSO periods are those periods with the highest actual and potential seasonal forecast skill over Australia.** This result leads to the question as to whether seasonal forecasting should only be made operational during the onset and duration of El Niño or La Niña events (ENSO periods), an approach followed by the Bureau of Meteorology in the earliest years of seasonal climate forecasting output in the early 1990s. This assessment result also follows, and is similar to, the results obtained by Bureau of Meteorology analysis of SOI phase forecast skill over longer time periods (Figs 1 and 2) and follows previous assessments of seasonal forecast potential by McBride and Nicholls (1983); Stone et al, 1996; and Fawcett and Stone (2010).

There are recognisable periods when the GCMs do not perform well. It is recommended these are periods when influences other than ENSO may dominate. Although it is recognised that there are limits to predictability in seasonal climate forecasting, it is strongly suggested additional attributes (e.g. the Quasi-Biennial Oscillation (QBO), Southern Annular Mode (SAM), Sub-Tropical Ridge (STR) be included in GCM development and operationalization as a matter of priority, if not already the case.

Based on this initial analysis, it is recommended that published and verified statistical seasonal climate forecast models be kept in an operational phase in parallel with developments and operation outputs of GCM forecast systems. It is also suggested that, based on other analysis (e.g. Schepen, Wang, and Robertson, 2012), that there is value in investigating the strengths of combining both statistical and dynamical (GCM) modelling approaches for forecasting Australian seasonal rainfall and this approach be investigated in terms of development of operational seasonal forecasting systems.

Based on this initial analysis, it is recommended that GCM-based operational forecasts at long lead times (e.g. three months or longer) be made operational in Australia, especially during the onset and duration of ENSO events.

It is considered that the contribution of other often important climate drivers (eg: latitude of the sub-tropical ridge, quasi-biennial oscillation (QBO)) may not yet be being captured by the GCMs at this stage of development. Inclusion of these additional climate mechanisms may add considerable value to the usefulness and skill of the GCMs forecasting systems for grazing systems in Australia.

Based on this initial analysis, it is suggested application of GCMs in management decision-making in Australia, especially for northern grazing regions, be preferred during the onset and duration of El Niño or La Niña (ENSO) years when GCMs may well be able to provide skilful and enhanced long-lead (three month before validity period) quantitative forecasts that are currently not available. In other words, as with statistically based seasonal forecasts, highest skill and opportunity for use occurs in years with a strong mechanistic signal, usually associated with major warming or cooling in the central equatorial Pacific Ocean. For southern grazing regions, GCMs appear to provide markedly improved forecasts over statistical systems. However, it appears that, especially in northern and eastern Australia, statistical seasonal climate forecast systems using SOI-based approached remain useful and valid as benchmark approaches and should not be discarded.

The prime conclusion is that a more lengthy and detailed time series assessment of forecast skill now be conducted covering a more lengthy period of real-time or modelled real-time independent verification (such as 15-20 years or longer). It will be also necessary to link these results to grazing management decision systems to as to assess the likely value of these forecast systems in management in the Australian meat and livestock industry. It should also be noted that GCM's provide output for additional forecast periods other than three months, notably for weekly and monthly validity periods that may well provide valuable input for tactical tie period decision making in the grazing industry. It is recommended that value analyses also be conducted for these other forecast period outputs.

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