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Long range and seasonal forecasting – is it improving?

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LONG RANGE AND SEASONAL FORECASTING
- IS IT IMPROVING?

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1. INTRODUCTION

It is undeniable that accurate and reliable seasonal forecasting would deliver significant tangible benefits to Australia's agricultural sector, including its grain producers. But is this tantalising prospect simply a holy grail forever elusive and beyond our grasp or are climate scientists making progress in improving our long range forecasting? Before we consider the question of whether seasonal forecasts are improving, however, we should spend some time outlining the nature and basis of seasonal forecasting by considering some other questions: Why is seasonal forecasting so difficult (and why particularly so for Australia)? Why and how indeed is it even possible at all? What makes a seasonal forecast good?

2. WHY IS IT HARD? – THE DIFFICULTY OF SEASONAL FORECASTING

There is of course a base predictability at the seasonal timescale due to the regularity of the earth's orbit and the constancy of the tilt of its axis which gives us our seasons in the first place. So we know with certainty in mid latitude regions that the average winter temperature with be lower than the average summer temperature. Overlaying this regularity however is significant variability, some externally forced (such as by volcanic activity), but much due to the chaotic nature of the atmosphere and oceans resulting in the daily, seasonal, yearly and decadal variations in weather and climate that pose such challenges to forecasters.

Compounding the difficulty in the Australian context is the relatively higher variability of our climate. Australia, due to its geographical location and the climate processes which influence it, has one of the most variable climates of any country, exhibiting considerable variations in rainfall, temperature, winds, cyclones and other weather phenomena from season to season, from year to year and also from decade to decade. This makes seasonal forecasting all the more difficult and yet at the same time all the more important for Australia!

3. WHY CAN IT BE DONE AT ALL? – THE BASIS OF SEASONAL FORECASTING

With the advent of Numerical Weather Prediction (NWP), the use of super computers running sophisticated mathematical models of the atmosphere, and with increasing availability of observations from satellites and other observational networks, great strides have been made in weather forecasting in the last three decades, with forecast skill 5 days ahead now as good as it was for 3 days in the early 1980's. Because of the chaotic nature of the atmosphere noted above, however, accurate numerical weather prediction is typically limited in practice to less than 14 days.

Given this the question we should be asking is not why aren't seasonal forecasts better than they are but why are forecasts with any skill out beyond 14 days possible at all? The answer to this question lies with the oceans.

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

Having said this, the predictability is limited. Most of this seasonal predictability in the Australian context is provided by ENSO, but this explains significantly less than half of the inter-annual variation across much of inland eastern Australia and even less elsewhere, and this also reduces the further out you look.

4. HOW IS IT DONE? - SEASONAL FORECASTING METHODS

There are two distinct approaches that can be used to generate seasonal forecasts – statistical and dynamical. The main characteristics of each approach are briefly outlined below.

4.1. Statistical approaches

There are a number of methods of producing seasonal forecasts which can all be classified under the general category of statistical approaches, including analogue techniques, stratified climatology techniques, regression techniques and the techniques used in the Bureau of Meteorology's current operational Seasonal Outlook,[1] principal component analysis and linear discriminant analysis.

What all these approaches have in common is that they use past observed relationships between slowly varying climate phenomena called predictors (such as sea surface temperatures), and various predictands (most commonly rainfall and temperature). Basically the past is used as a guide to the future.

These methods require a sufficiently long period of good quality observational data to establish the predictor/predictand relationship with sufficient statistical rigour. This period is often termed the "training" period and generally a period of about 50 years is used. Significantly longer periods are not currently possible because of the paucity and quality of the observational record, particularly of the oceans, prior to the second half of the 20th century.

Statistical methods assume that the predictor/predictand relationship is stationary and that the training period used captures the range of climate variability.

A feature of statistical seasonal forecasts which they have in common with most other seasonal forecasts is that they are probabilistic in nature rather than the categorical type of forecast people are more used to in weather forecasting.

[1] Current Seasonal Outlooks along with explanatory material can be found at: http://www.bom.gov.au/climate/ahead/rain_ahead.shtml & http://www.bom.gov.au/climate/ahead/temps_ahead.shtml

4.2. Dynamical approaches

The second major category of seasonal forecasting methods is the dynamical approach. Here, much as with NWP, the system is modelled mathematically on a super computer, with the relevant physical equations used to project the climate system forwards in time from initial conditions. One difference with NWP climate prediction is that due to the time scales involved changes in the oceans and even land surfaces need to be explicitly included (on NWP time scales these are generally assumed to be negligible), and hence coupled atmosphere and ocean models are required. The spatial resolution of climate models is also typically less than for NWP to allow for the longer temporal run (out to several months as opposed to several days). Also the skill of predictions of climate (e.g., average weather for a month rather than on a particular day) retain skill for longer into the future than high resolution (e.g., daily) predictions. Thus, dynamical seasonal forecasts tend to involve statements about average conditions over future weeks to months rather than forecasts of specific weather. In this regard they are similar to statistical approaches which also provide probabilistic forecasts as noted above.

Although dynamical climate models are initialised with current conditions from the atmosphere and oceans, the chaotic nature of the climate system means that you still run into the issue faced in NWP – as the model is not a perfect representation of the system (either in terms of equations or the observations) even the smallest errors will inevitably grow over the period of the forecast. This is generally handled in dynamical seasonal forecasts by “ensembling” consecutive model runs (often up to 30). The re-initialisation of the model with new conditions for each run is effectively like a perturbation of the initial conditions, and serves to reflect the level of uncertainty in not being able exactly prescribe these initial conditions. The spread in the forecast runs can then be analysed and provide estimates of probability in forecast outcomes for particular variables. These ensemble predictions generally provide more robust and reliable assessments of forecast conditions but are of course necessarily probabilistic. Ensemble runs are often displayed as forecast plumes for the particular variable, such as sea surface temperature spatially averaged over a particular area.

One other potential advantage of the use of dynamic models is that they open up the possibility (yet to be realised, however) of seamless forecasting across all timescales, from daily to weekly (for weather), through intra-seasonal and seasonal, through to inter-annual and inter-decadal.

Most of the current operational forecast products provided by the Bureau of Meteorology's Climate Services Program are based on statistical forecast methods that have been used for more than two decades. As will be discussed further below, some new, experimental dynamic forecasts are showing improved forecast skill and are expected to replace statistical forecasts in the future. They are currently used to provide additional guidance for the operational service, particularly in relation to conditions in the tropical Pacific and Indian Oceans.[2]

[2] See http://www.bom.gov.au/climate/coupled_model/poama.shtml

5. WHAT MAKES A GOOD SEASONAL FORECAST?

Two factors need to be considered in assessing how "good" a seasonal forecasting system (whether statistical or dynamical) is and whether it can be said to be improving. Firstly, its quality or accuracy measured in terms of both forecast skill and reliability. But secondly, and just as importantly, its value – how useful is it to users?

5.1. Skill and reliability

Skill is a measure of the accuracy of forecasts relative to the accuracy of other forecasts using a reference method (e.g. guessing, persistence, or climatology or other methodology). There are numerous measures of skill and the skill of seasonal forecasts typically varies both spatially and temporally (i.e. methods will do better at some locations at some times of the year than at other times or locations).

Reliability on the other hand is the degree of correspondence between the *a priori* predicted probabilities of an event and its *a posteriori* observed relative frequency. For example if a forecast of above median rainfall is issued with a 70% probability we would expect above median rainfall to occur on 70% of occasions if the forecast system is reliable. It is possible for a forecast to have good skill but low reliability.

5.2. Value

In assessing whether a seasonal forecast is "good" more than its accuracy must be considered. I can with 100% certainty and reliability forecast that average winter temperatures at a certain location will be lower than average summer temperatures at that location, but such a forecast would be next to useless as it tells the user nothing more than they would know already. The value or utility of a forecast must also be considered in assessing how good it is. Skilful seasonal forecasts can be used to maximise benefit in good years as well as avoid losses in bad years. A seasonal climate forecast can be used to determine the optimum time to sow, the area sown and the amount of fertilizer that might need to be applied. Value can be given a numerical measure, for example the impact in dollars that prudent use of a given forecast scheme has on the user's profits compared with profits made using a reference strategy.

Another attribute of a forecast that is related to the issue of its value is clarity of communication - how understandable the forecast is by the intended user group. A forecaster's job is not done once they have produced a forecast, no matter how accurate it is and how useful it might potentially be, but when it is clearly communicated so as to be understood and so used by the end user.

6. ARE SEASONAL FORECASTS IMPROVING?

The question then of whether seasonal forecasts[3] are improving has two aspects – are they improving in skill and reliability? And are they improving in value?

[3] For the purposes of this paper I will reserve specific comment to the Bureau of Meteorology's seasonal forecasting systems and plans.

6.1. *Is skill and reliability improving?*

Before looking at individually at statistical and dynamical seasonal forecasting it is worth noting that both have benefited significantly from the huge increase in the observational data available in real time and across previously data sparse areas such as the Indian Ocean over the last few decades. Australia's seasonal forecasts depend greatly on international observation systems, such as satellites, Argo ocean profiling sensors, and especially the TAO/TRITON tropical moored ocean sensing array, which is crucial for crucial for Pacific and El Niño and Indian Ocean Dipole forecasting systems. Seasonal forecasts of any useful timeliness have only really been possible with the advent of this data stream over the last few decades.

6.1.1. *Statistical approaches*

Most operational seasonal forecasts currently delivered by the Bureau are based on statistical forecasting, using methods developed and implemented since 1989 by the National Climate Centre (NCC). The NCC issues seasonal (three-month) rainfall and temperature outlooks each month using the format of the probability of exceeding the long-term seasonal median. The current operational system has been in place without significant change since 2000 and uses the two statistical techniques of principal component analysis and linear discriminant analysis. It explicitly includes the states of both the Pacific and Indian Oceans.

The choice of the 3 month forecast period is a compromise between competing criteria - predictability goes up as time period goes up, but the forecast becomes less useful. Predictability also drops off rapidly with increased lead time for the forecast. A three month forecast at lead of 0 or 1 month is about as good as can be done (so as much as we might like to there is no point in producing a winter outlook in summer, for example).

NCC undertakes routine verification of the operational forecasts[4] from which it can be seen that skill varies spatially and with season but also on inter-annual time scales. A few different methods or variations have been tried internally, none showing any major improvements on the current operational method. The existing operational seasonal forecasts for Australia appear to have reached their peak level of performance and may even be declining in skill, an issue which will be touched on below.

A key assumption of statistical forecasting is that past weather and climate patterns are sound indicators of what can be expected in the future in at least two respects. Firstly, statistical forecast schemes, as noted above, typically assume a stationary climate to make the statistical connection between predictors and predictands but these statistical relationships can be variable over space and time. Secondly, it is assumed that the training period captures the range of the climate variability – this can be invalidated if there is a substantial secular change in the climate that is not represented in the training period or if climate change means that the system is moving increasingly outside the bounds of past experience. Both of these factors may be impacting on the skill of the operational seasonal forecast system.[5]

[4] See http://www.bom.gov.au/silo/products/verif/ for more discussion on this.

[5] The training period of the operational system is of necessity 1949 -1999 (significantly prior to this insufficient data is available) but we now know this corresponds with a particularly wet period for much of eastern Australia in the historical record, whereas the first half of the 20th century was significantly drier.

Due to this stalling and possible decline[6] in skill recent initiatives in the Bureau and in other National Meteorological Organisations are focused, therefore, on developing dynamical seasonal prediction models. As these do not rely on the past as a guide but the physics they should be able to take account of a changing climate.

6.1.2. Dynamical approaches

Dynamical seasonal forecasting is based on the fundamental physical and dynamical relationships of the components of the climate system and as such have distinct advantages over statistical forecasting as they can predict new situations and cope with a changing climate regime. They can also in principle produce forecasts with greater lead times and with a greater variety of and shorter forecast periods. The disadvantage is that they require super computers to run and are in many ways "cutting edge."

The Bureau's dynamical model is known as POAMA[7] and has been used operationally since 2002 (along with the major international dynamic models) to provide forecast guidance on the state of ENSO and the Indian Ocean.[8] POAMA's skill at ocean forecasting is high and it has been doing a good job at forecasting ENSO[9] (though not so well on ENSO impacts). Other forecasts from POAMA are available through the Bureau but are still generally classed as 'experimental' [10] because some key products generated by the modelling systems are assessed as insufficiently reliable to replace similar products generated using the statistically based forecast system.

POAMA is run once every day and produces ocean and atmosphere forecasts out to 9 months. As most physical interactions are simulated in the model based on the laws of physics it produces a wide range of forecast variables. The last 30 forecasts provide an ensemble from which probabilistic forecasts can be made.

Analyses of the experimental dynamic seasonal forecasts to date indicate that their skill over Australia is approaching or in some locations and seasons exceeding the statistical system but the uncertainty attached to some dynamic forecasts is suspected of being too low. That is, there is concern that the dynamic forecasts have low reliability or are 'over confident' and convey to users greater certainty about future conditions than is warranted. Work is on-going to improve POAMA (now at version 2) and various possibilities are being examined to improve the forecasts including things such as improving the model physics, higher resolution, better initialisation and data assimilation, and more hindcasts.

The focus of the next phase of development (POAMA-3) will be to include the seasonal forecasting system within the Australian Community Climate and Earth System Simulator (ACCESS) that is being developed by the Centre for Australian Weather and Climate Research (CAWCR)[11] in collaboration with several universities to provide Australia's next generation weather prediction system and the next generation climate change simulation system.

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[6] The detailed work to demonstrate a decline in skill and its cause have not been formally done.
[7] Predictive Ocean Atmosphere Model for Australia.
[8] See http://www.bom.gov.au/climate/coupled_model/poama.shtml and http://www.bom.gov.au/climate/ahead/ENSO-summary.shtml.
[9] Skill for El Nino related forecasts has been evaluated from retrospective forecasts and is useful out to at least 9 months into the future.
[10] Experimental dynamic model outputs can be viewed at http://poama.bom.gov.au/ but please note these are experimental and should not be used for decision making until such time as they are issued as operational products.
[11] CAWCR is a collaborative partnership between the Bureau of Meteorology and CSIRO.

ACCESS is already delivering much-improved short-term weather forecasts compared with the current operational system and is expected to deliver significantly improved capability in generating seasonal forecasts. Both aspects of ACCESS are expected to be enhanced significantly by improved and more diverse data assimilation from various land, ocean, automated and satellite sources of observations.

ACCESS will provide Australia with a common simulation platform for delivering weather forecasts as well as seasonal climate predictions and longer-term, multi-decadal climate projections. There is optimism that the dynamic seasonal forecast element of ACCESS will in the next few years produce regional products with sufficient reliability to completely replace the existing statistical approach.

Other possible developments which have the potential to lead to improved forecasts are:

- Multi model methods merging or blending forecasts from several models may lead to increased skill and reliability.
- Hybrid models where dynamic and statistical approaches are combined.

6.2. *Is forecast value improving?*

As noted previously, skill and reliability are not the only determinants of how a forecast is assessed - there is also the value of the forecast to consider.

There are a number of Issues that impact on the real or perceived forecast value of the Bureau's statistical Seasonal Outlook products, including:

- Probabilities are most often not far from 50% – this means that guidance is often close to climatology. However, knowing this can be of some value, indicating there is not a strong signal shifting the odds towards wetter or drier conditions.
- The forecast lead time can be too short for some decisions – however, as the skill of the statistical scheme declines rapidly with lead time, a longer lead time would not provide greater value.
- The forecast period (3 months) is too long – in situations where timing and distribution of rainfall, for example, is highly significant the forecast gives no guidance. However, as noted previously, reducing the temporal resolution reduces the skill.
- The forecast gives no guidance on the chances of extreme events – these are often the events that determine profit and loss.

The above issues are unlikely to be removed or significantly reduced while using the statistical approach, however, they all potentially can be addressed at least partially with dynamical methods and so significant improvement in value in connection to these issues may be expected as the shift to dynamical forecasts occurs. Key challenges to enhance the utility of seasonal forecasts for users include not only improving the skill, timeliness and delivery of the forecasts but also improving communication and understanding for users about the appropriate interpretation and use of the valuable but uncertain information contained in seasonal forecasts (whether statistical or dynamic).

Some issues relevant to the value of seasonal forecasts where improvement is possible include:

- Confusion over the probabilistic nature of the forecasts and associated uncertainty. The limits to skill and the inherent uncertainty of seasonal forecasts are not generally well understood by end users. Seasonal forecasts will be most valuable and informative if their uncertainty is well-understood, well-communicated and well-used. Hence, education of end-users in the best use of forecast probabilities is essential. This also applies, of course to probabilistic forecasts from dynamic forecasts
- Limited usefulness of the above/below median presentation of forecasts. New methods for displaying probabilistic seasonal forecasts have recently been developed by the Bureau, including the probabilities of exceeding certain rainfall thresholds and outlook scenarios at different probabilities. These offer more intuitive ways of viewing outlooks in a probabilistic framework.[12]

Finally, it is clear that end-user participation in the development of the information products derived from the forecasting model, whether statistical or dynamical, will provide considerable benefit in terms of their ultimate value as assessed by end-users.

7. CONCLUSIONS

The current skill of seasonal forecasts in most regions of Australia is currently only moderate and, even so, varies throughout the year. Further, the probabilistic terms in which these forecasts are usually expressed are often not well understood, which can lead to a lack of confidence in using them for practical decision making. The latter can be addressed through greater end-user consultation and education, the former stands the most chance of being addressed with further improvements in dynamical seasonal forecasting and a consequent shift to these dynamic models for operational forecasting. Even so, improvements in skill and reliability are likely to be evolutionary rather than revolutionary. The levels of certainty we might wish for in our seasonal forecasts will in all likelihood remain an alluring prospect - an elusive holy grail veiled by the chaotic nature of the climate system.

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[12] See the WATL pages at http://www.bom.gov.au/watl/rainfall/exceedance.html.