Use of seasonal forecasts for guiding early season decisions in Australian cotton systems

Chris Nunn [1*], Jaclyn N. Brown [2], Peter McIntosh [3], Kavina Dayal [2], Michael P. Bange [1]

[1]CSIRO Agriculture and Food, The Australian Cotton Research Institute, Locked Bag 59, Narrabri, New South Wales, 2390, Australia.
[2]CSIRO Agriculture and Food, Private Bag 12, Hobart, Tasmania, 7001, Australia.
[3]CSIRO Oceans and Atmosphere, Retired.

*Corresponding author (christopher.nunn@csiro.au).

Abstract
Australian cotton production is characterised as a high-value, quality product, earning in excess of $2.5B in exports annually. High year-to-year variability in rainfall and temperature influence productivity which could be managed more effectively with appropriate foresight. Seasonal climate forecasts have the potential to equip growers with upcoming season knowledge to mitigate risk but also to implement less risk averse behaviour in good years. Here we outline the key decision points where a seasonal climate forecast of temperature and rainfall could provide actionable insights. We further test the skill and reliability of Australia's current seasonal climate forecast system to provide this information at four key locations: Moree, Griffith, Dalby and Emerald compared to the SILO record of weather from 1981-2017. Model predictions were assessed in terms of correctness and also how emphatic the prediction was. In many cases the range of predictions offered across the POAMA ensembles is so large that variation in the median is overshadowed, leading to a flattened response across years. This offers little advantage over the current approaches that use climatology as a guide to the future. Advances in climate modelling need to address both the predictive skill and the broad prediction envelope to offer useful advances in this field.

Introduction
Australian cotton is a high value and intensively managed broadacre system. Australian climate has always delivered large year to year variations influencing yield and management responses. With recent climate change trends now and into the future, greater uncertainty exists in how each season will unfold. Previous methods relying on looking to the past climate to understand the future may not be relevant under an evolving new climate regime. Here we focus on the challenge of early season crop establishment and development, where the progress of the crop is driven primarily by soil temperature before emergence and air temperature thereafter.

Early in the cotton season important decisions are made to determine when to sow the crop and how to respond to crop progress for crop nutrition, pest, and canopy size management. A timely decision for planting ensures the best chance for successful establishment, where planting too early can lead to delayed emergence – with corresponding increased pest and disease risks - or even a failed crop. Planting too late risks losing potential yield or even extending the end of the season with corresponding risks to quality. Once the crop is established, identifying when it may reach critical stages of crop development will influence the management response and inputs from growers early in the season to improve yield outcomes and manage costs (e.g. pesticides).

We explore the current capability of a dynamical seasonal forecasting model (POAMA, (Hudson et al., 2017b)) to provide early season temperature predictions for these tactical decisions. Four regions that span the Australian industry (Emerald, Griffith, Moree and Dalby) are taken as case studies using retrospective daily temperature forecasts from 1980 to 2017. Forecasts were generated from the start of September through Oct to Nov, to predict the time when the first developmental events occur (historically ranging from Dec to Jan).

Methods

Study region and climate regimes.

The study is conducted for four stations representing the range of climate zones for Australian cotton - Emerald, Dalby, Moree and Griffith (see Figure 1a). The main areas of Emerald, Dalby, and Moree are in the temperate – hot summer – climate region, but are all on the edge of the arid hot steppe area (Beck et al., 2005). Griffith, the most southerly location, is right in the middle of the arid cold steppe region. Historic (1981-2017) weather data was obtained from the SILO database (Jeffrey et al., 2001) and used as a baseline to assess the skill of the climate forecast for each location (Figure 1b).

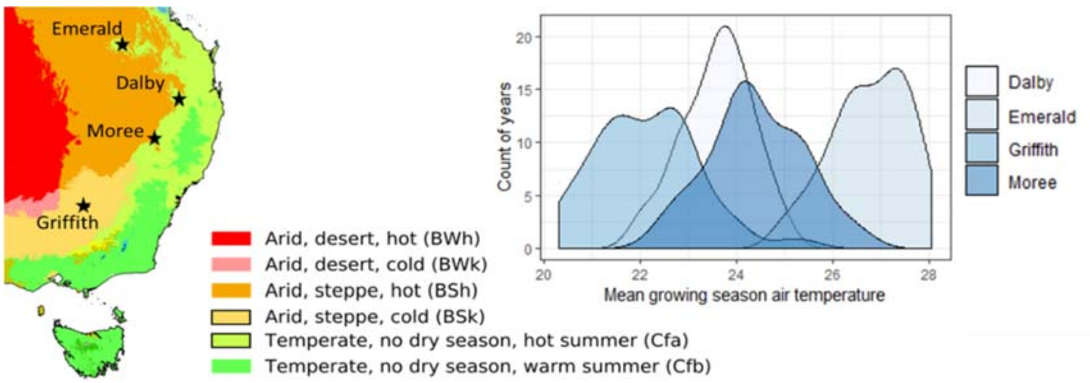

Figure 1. a) Map of cotton growing regions in Australia and our four case study locations at Emerald, Dalby, Moree and Griffith with Köppen–Geiger climate classification areas. b) Frequency distribution of average growing season (October – May) temperatures at each location for the years 1981-2017.

Climate and cotton modelling

We use the POAMA Operational Coupled Model Seasonal Forecast System developed by the Australian Bureau of Meteorology and CSIRO (Hudson et al., 2017b). Using a forecast date of 1st September, the forecast contains a spread of 33 ensembles for rainfall and temperature generated by varying the forecast start date and used to predict 9 months for the season ahead. The horizontal resolution of the model is 250 km so this model output was downscaled and calibrated to local weather stations using a quantile mapping approach (www.agforecast.com.au, (McIntosh and Brown, 2014)). Analysis of early season POAMA predictability related to: time of emergence, timing of first square, flower and open boll. The developmental stages were predicted using simple cotton development models (www.cottassist.com.au) based on thermal time after a sowing date of 1st October.

Forecasting Assessment

To assess the probabilistic spread obtained from the forecast model, we followed the approach of Brown et al. (2018), categorizing each year of the historic record as top 20%, lowest 20% or mid-range. The POAMA forecasts were then categorized to the same scale and the number of ensembles in each category assessed. The forecast was deemed as either correct, one-out or misleading (for example when a cold year was predicted as hot), depending on which category most ensembles fell. Finally, no one category held a majority of the model ensembles, we deemed the forecast 'inconclusive'.
To assess the climate model compared to climatology, the median days from sowing of the SILO data for each location for each developmental stage (emergence, first square, first flower, first open boll) was calculated. This was compared to the median of the POAMA ensembles for each year, counting the number of years where a prediction fell within 2 days and within 7 days.

Results

Early season temperature prediction

Climate prediction of temperature was generally successful, with the majority of results in Griffith and Emerald in the correct band and few misleading results at any location (Figure 2). However, there were a large number of inconclusive results, especially at Dalby, where the model was inconclusive more years than any other result.

Early season rainfall prediction

For rainfall predictions, the uncertainty was much higher, with an inconclusive result for the majority of years at all locations except Griffith, which is the only location where a correct prediction was likely (Figure 2). Misleading results were also more common, and at Emerald, the forecast gave a misleading result in more years than it gave a correct result.

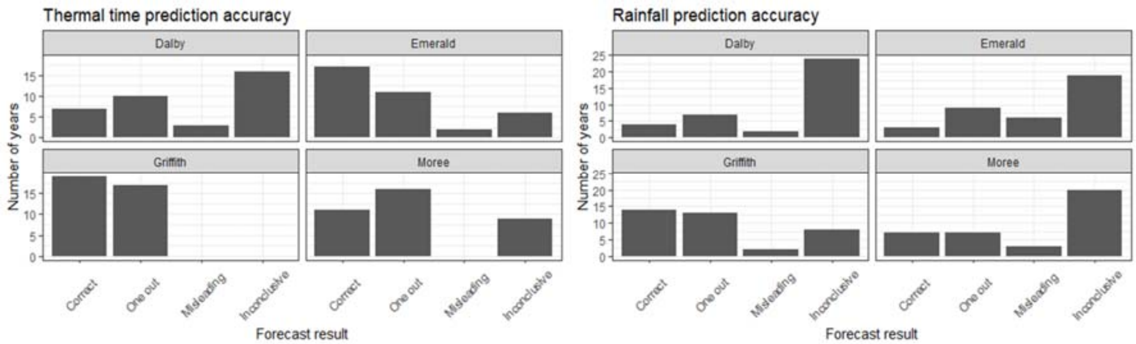

Figure 2. Summary of model performance at predicting thermal time and rainfall at each of four case study locations based on the number of correctly predicting ensembles.

Early Season Cotton Development

Using s degree days calculation, first square historically occurs earliest at Emerald, then Moree, Dalby and Griffith. The median POAMA predictions were generally close to the actual data, especially in the average years. However, in cooler and warmer years, the model did not correctly match the extent of the extremes, both high and low. The result was closest at Moree when predicting first square and first flower ($R^2 = 0.26$) (Figure 3).

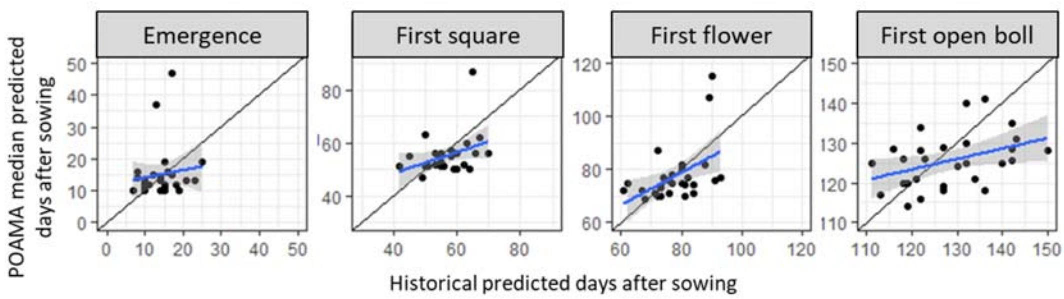

Figure 3: Plotted days after sowing for emergence, first flower, first square and first open boll days after sowing based on the SILO recorded degree days for Moree against the median of the 33 POAMA ensembles for each year (1981-2017). The shaded area shows one standard error from the fitted line

POAMA compared with climatology

When comparing the cotton development predictions of POAMA with the historical average, the results varied by location. At Emerald, POAMA was better than climatology at predicting all stages of crop development (Table 1).

Table 1: Table of accuracy of POAMA and climatology for predicting developmental stages of a cotton crop at four locations. Shows percentage of years (1981 – 2017) where prediction was within 2 days of the recorded weather data based on a planting date of 1st October.

Location	First square		First flower		First open boll	
	Climatology	POAMA	Climatology	POAMA	Climatology	POAMA
Dalby	25%	21%	29%	25%	19%	19%
Emerald	46%	79%	43%	57%	14%	39%
Griffith	11%	32%	14%	36%	18%	-
Moree	18%	32%	14%	21%	14%	25%

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At Dalby, Griffith and Moree, both climatology and POMAMA had poor results, with a prediction within 2 days in less than 40% of years. At Dalby, POAMA performed worse than climatology. At Moree and Griffith, POAMA performed better than using the historical average for all stages. At Griffith, due to the slow growth rates, it was common that the thermal time to first open boll extended beyond the POAMA forecast.

Discussion

Use of climate forecasting improved identifying the first flower date compared to the average predicted time based on history. Predictions of rainfall were less successful than for temperature, due mainly to the lack of a conclusive prediction across the ensembles. Research continues to better identify those regions where the forecasts will add value and to understand where these forecasts can be applied in other parts of the cotton season.

Here two methods were used to assess forecast performance, quantitative and qualitative. For early season cotton development, a qualitative degree day approach was used. However, this accumulation of temperature from the date of sowing also accumulates the error, meaning that any bias in the forecast can be exaggerated, leading to missed targets. This is where the qualitative assessment becomes useful, forecasting a warmer/colder or wetter/drier season and through the spread of ensembles, the uncertainty. A forecast system with a high number of misleading forecasts would be extremely disadvantageous compared to simply looking at past climate patterns.

Early season cotton management could benefit from upcoming season temperature information from September to January. The current seasonal climate model POAMA is limited in its ability to provide insights during this period. The low skill from the model is more due to inconclusive than incorrect forecasts. There is a tendency for the ensemble members in the forecast to predict a large range of possible futures, meaning that the model median too often results in a forecast of average conditions. In these situations, the climate forecast has little to offer beyond what can be found from a climatology approach.

Research into agricultural applications of seasonal climate forecasting has unveiled challenges in the properties of the weather that is generated by seasonal climate models. There have also been concerns about the application of quantile mapping for calibration of the model output as not necessarily capturing the features of the extreme events. New models are now becoming available (e.g. ACCESS-S, (Hudson et al., 2017a)) run at higher resolutions and with a focus on the sub-seasonal time scale. This may advance the applicability of seasonal forecasts to the cotton industry.

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