Practicing agronomy in an uncertain climate – Using simulation modelling to study seasonal drought and the impact of ENSO in the Southern Australian grains belt.

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Abstract
Climate variability adds a level of complexity to the agronomists' tasks of running field trials, interpreting results and making recommendations for farmers. Increasing attention to the evidence that climate is changing makes thinking about risk in the practice of agronomy more important, but also more difficult. The South Australian agronomist Reg French made a call 20 years ago for better understanding of climate and access to better models that translated climate data to yield and economics. The simulation model APSIM was used to investigate the pattern of seasonal moisture stress during the growing season for four medium to high rainfall and four low rainfall sites in the Southern Australian grains belt. Cluster analysis showed four broad season types; low moisture stress early and late (LL), low early and high late (LH), high early and low late (HL) and high early and late (HH). We analysed the relationship of El Nino Southern Oscillation (ENSO) to these season types and to regional rainfall. In conclusion we reflect on some implications of a non-stationary climate for agronomists as we use knowledge from past seasons to work with farmers on plans and decisions for the coming season. Neither simulation modelling nor climate science will predict a single future outcome, but they may be able to assist in quantifying an uncertain future with risk profiles for different cropping decisions.

Key Words
Seasonal drought, climate risk, El Nino Southern Oscillation

Introduction

Few would argue with the challenges posed by the theme of this section; *Farming* in an uncertain climate. Year to year and decade to decade variability in climate makes decision making difficult for farmers. Recent seasons have led to considerable hardship for most grain farming enterprises. The estimated loss in 2005/6 (ABARE 2008) for the average Australian grain businesses was $373 followed by a loss of $ 83 000 in 2006/7. Higher commodity prices led to an estimated profit of $48,000 in 2007/08 (ABARE 2008).

The focus of this paper is *agronomy* in an uncertain climate. Many of the challenges for agronomists are closely linked to difficulties for farmers. An increasing number of agronomists' livelihoods directly depend on payments for services to farmers and there is no doubt that there is personal stress for people working closely with farmers. Apart from the obvious point that the wellbeing of farmers and those servicing farmers are linked, climate variability presents a particular suite of challenges for agronomists. Core activities of interpreting field experiments and providing advice for farmers are tasks that would be easier, or at least significantly different, if the climate was less erratic.

Trying to make sense of results from field trials in a variable climate is made even more difficult by the trend over recent decades away from longer term experiments at research stations toward various forms of short term on-farm research. The philosophy, advantages and disadvantages behind this trend toward localised and participative research has been widely discussed (Carberry 2001; Geurin and Geurin 1988; Hamilton 1995). Although there are many advantages in developing relevant science with end users, one of the trade-offs that has not received as much discussion has been between a higher degree of spatial representation and a lower degree of temporal representation. Williams (1994) referred to the tyranny of site and season; we are sampling a higher number of sites, but fewer seasons on the same site. An extreme example of long term trials is Rothamstead which has been used to study climate change (Chmielewski and Potts 1995). This can be contrasted with any three year funded project started in 2005 in Southern Australia which sampled three seasons; two promising starts and a disappointing finish and one with a poor start but good finish. Making robust conclusions from even well run trials can be difficult.

Separating out signal from noise in a variable climate is well documented in agricultural science in Australia. Some examples are as follows:

- Wockner and Freebairn (1991) measured runoff and erosion for 14 years (1976-1990) on the eastern Darling Downs. They found that 70% of the 556 t/ha of soil loss from a bare fallow wheat-system occurred in only six storms.
- Clewett et al. (1995) used the simulation model GRASSMAN to show decadal shifts in optimum stocking rates in central Queensland ranging from 10 to 30 head of cattle per 100 ha, concluding that such variation made learning from graziers' own, or even their parents' experience, problematic.
- McCaskill and Blair (1988) noted the bias of the 1950s, 60s and 70s in experimental work, extension programs and data for models on superphosphate and stocking rates in the northern tablelands of NSW. Across most of eastern Australia this was a wetter period. They recommended the climatic conditions prevalent between 1900 and 1949 should be taken into account when assessing management options.

This challenge of interpreting field results and providing guidance for farmers is hard enough in a stationary but variable climate, it is even more difficult in a changing climate. Milly et al. (2008) observed that accepting non-stationarity of climate, and in doing so abandoning the notion that climate fluctuates, but within an envelope of variability, challenged the basis of planning and risk assessment that permeated training and practice for water engineers. The agricultural risk assessment that most agronomists have been exposed to recognises that climate is variable, even cyclical, but over a long enough period assumed to be stationary. In many cases this may be a reasonable assumption, but climate change will challenge this in the future and decadal variability means that it was always problematic.

The agronomist as risk analyst

Agronomists are increasingly being asked to not only have expertise in productivity and environmental management, they are also being asked to be risk analysts. This involves more than just being cognisant of risk, or aware that things can go wrong, but to explicitly address the issue of risk and reward. A farm enterprise is primarily concerned with business risk which has a component of production risk, price risk and financial risk (interest rates). Recent rapid rises in fertiliser costs suggest that cost risk should also be added to this list. While the main focus for the agronomist is production risk, price and production risk can have a negative interaction. The 2007 winter cropping season was an example of this when a number of grain growers had managed price risk with forward contracts but had much lower production than expected.

The Macquarie Dictionary defines risk as the chance of loss (Delbridge et al. 1991) and this is consistent with a common role of risk assessment in environmental or health and safety planning as being a hazard multiplied by the likelihood of the hazard occurring. Most production economists would have a broader notion of risk as the variability in an outcome for a given decision. In his text on the concepts of risk Bernstein (1996) notes that risk comes from the Italian *riscare* to dare and emphasises choice, opportunity and gain as much as fate and loss. He maintained that one of the key revolutionary ideas that defines the boundary between modern times and the past is that the future is more than a whim of the gods, and that the rewards and risk for different ventures could be weighed, compared and factored into decision making without consulting oracles and soothsayers who had previously had a monopoly on knowledge about the future.

The budgeted return for planting a given crop with a level of inputs is almost always wrong. The numbers in the budget will be an underestimate or overestimate by a small or large amount. In their seminal text on Agricultural Decision Analysis, Anderson et al. (1977) maintained that the key questions for any decision in agriculture could be summarised as "What choices, what chances, what consequences"? Agricultural scientists have tended to focus on a single consequence for a given choice- if you add X amount of fertiliser the yield will be Y. A more complete picture is offered by the statement if you add X amount of fertiliser, depending on the season, the result will be Y1, Y2 or Y3. It is the uncertainty and the range of outcomes, both for the farm business and the environment that presents the challenge for the agronomist. Yet there is ample evidence from the psychology literature that humans are not good intuitive statisticians and we struggle to deal with concepts of risk and probability, especially for rarer events with major consequences. These biases have been related to climate Hayman and Cox (2005); Nicholls (1999); White (2000) and a summary is shown in Table 1.

Table 1. Perceptual biases (modified from Hayman and Cox 2005)

Bias	Description
Availability	Events experienced first (primacy) or last (recency) assume undue importance. The run of seasons when a farmer or agronomist first moved to a region or the recent run of seasons, especially if unusually good or bad is likely to affect what is expected as normal.
Selective perception	We tend to seek information consistent with own views. Some farmers and agronomists have strong views on cycles of floods and droughts and look for confirming evidence. Recent weather events can be used to confirm or deny preconceived notions on whether climate is changing.
Concrete information	Vivid, direct experiences dominate abstract information; a single personal experience can outweigh more valid long term statistical information. We are all likely to remember the booms and droughts more than the average years.
Law of small numbers	Small samples, especially recent history that is readily available to a decision maker are seen as representative of the larger population. We struggle to put a short run of seasons into context, especially if trial results come from those three years.
Insensitivity to base rates	In dealing with uncertainty we tend to ignore background information, for example the media reporting of the forecast of a wet or dry summer can ignore the background chance of a dry hot summer in a Mediterranean climate. Likewise there have been about 24 El Niño events in the last century and by definition, only 10 bad droughts (decile one or worse). So El Niño means increased chance of drought rather than guarantee of drought.
Gambler's fallacy	People can be convinced of patterns that don't exist for example, that random events are self-correcting. If a coin has been tails three times in a row, people will bet on a head with the hope that the coin remembers. The confidence for the 2007 season in Southern Australia was due in part to the excellent start but also to a notion that a good season was due.

Most of these biases relate to imperfect sampling whereby we are prone to use the wrong probability distribution to derive the likelihood of an event. Some of these biases that give a higher weight to recent events,may actually help in a changing climate, but the psychology literature on human judgement suggests that we are likely to over or under adjust our estimates of future climate depending on our underlying perceptions about climate change and the run of recent seasons.

To this point in the paper we have reached a rather pessimistic conclusion that can be summarised as follows:

- Most field experiments are too short to sample seasonal variation.
- Most agronomists don't live long enough in one location
- Even if we do live long enough, as humans we have demonstrably unreliable memories of the past and consistently perform poorly in thinking about risk in the future.
- Even if an agronomist had lived long enough in one location, been funded to run a very long term field experiment and had rare skills as an intuitive statistician, climate change acts to erode some of the value of the information.

To counter this pessimistic view in the rest of this paper we look at some of the tools that are available for agronomists to manage risk. Twenty years ago French (1987) considered appropriate R&D for drought preparedness in South Australia. He pointed to better understanding of seasonal climate variability and modelling. *"One of the biggest deficiencies in agricultural research is the inability to both predict the probability of rainfall during the growing season and to estimate the yield and economic returns of different crops"*. He saw a need for a *"study of the variability of weather patterns"* and while recognising that simple models for predicting crop yields existed, he urged the development of models that *"use farm weather data during the growing season and progressively estimate the likely yield and economic return"*.

What does climate science have to offer the agronomist in risk management?

There is an enormous national and international effort focused on better understanding climate change at a regional level. One of the benefits of this effort is likely to be better seasonal forecasts. Almost a century before Reg French called for seasonal climate forecasts, another eminent South Australian Sir Charles Todd (1893) stated that *"the importance to the farmer, the horticulturalist, and pastoralist of knowing beforehand the probabilities of dry or wet seasons, and whether the rains will be early or late, or both, has naturally led to a desire for seasonal forecasts. They have them, it is said, in India; why not in Australia?"* cited in Allen et al. (1996)

It is likely that both Reg French and Sir Charles Todd would be disappointed with the current status of seasonal climate forecasts. Although over 50% of farmers use seasonal climate forecasts (see Hayman et al. (2007) for a summary of surveys) the guidance from climate science can be summarised as too good to ignore, but not good enough to carry much weight in decision making. One of the main frustrations by users of the forecasts in Australia is that the forecasts are rarely emphatic, in other words there is too much time when the forecast odds are close to the odds from long term climatology. In August 2006 the Australian Academy of Science held a workshop on the Science of Seasonal Climate Forecasts (Manton et al. 2006). This workshop concluded that ENSO currently provides the scientific basis for seasonal climate prediction and that further research should clarify the roles of additional potential seasonal predictability in the Australian region, these are likely to be the Southern Annular Mode (SAM) and the Indian Ocean dipole (IOD). The Bureau of Meteorology Water and the Land website (www.bom.gov.au/watl) provides information on a range of climate drivers for Australia. The IOD and ENSO are coupled atmospheric ocean systems whereas SAM is an atmospheric system that fluctuates on a fortnightly timescale and hence is more difficult to forecast on a season by season basis. The workshop also concluded that the future lay in forecasts from dynamic climate models rather than statistical models, as dynamic models become more sophisticated they will include the interactions between the ocean and atmosphere that drives climate in southern Australia.

In the methods and results section of this paper we investigate the impact of ENSO on APSIM simulated season types and rainfall in the region. As discussed in Hayman et al. (2008), the Indian Ocean and Southern Annular Mode are important drivers of climate for the southern grains region. The focus on ENSO in this paper is partly in the interest of space and scope but mainly because discussion about new climate information has led to a mistaken assumption that ENSO does not have an impact in the region. In a historical account of the difficult development of ENSO based forecasts Nicholls (2005) muses on how difficult it was to have ENSO recognised over the last two decades but now it seems too easy to suggest new predictors. ENSO is the most studied and monitored system and there is a large international effort in predicting the status of ENSO and this is available from about February or March each year from the Bureau of Meteorology El Nino Update (http://www.bom.gov.au/climate/enso/). Although predictions of ENSO are far from perfect, it remains the basis of most operational prediction systems and it is well worth asking the question as to whether farmers and agronomists should pay any attention to a warning of an increased chance of El Nino.

What does simulation modelling have to offer?

The Yield Prophet model (the web based interface for APSIM www.yieldprophet.com.au) used by more than 1000 farmers and consultants over the past 5 years could be seen as partially addressing French's request for a model that is updated as the season progresses (Hunt et al. 2008). Figure 1 shows that there are a large number of commercial crops that Yield Prophet has been applied to and, although far from perfect, it provides a very useful estimation of final yield. Yield prophet is more fully described in Hunt et al. 2008).

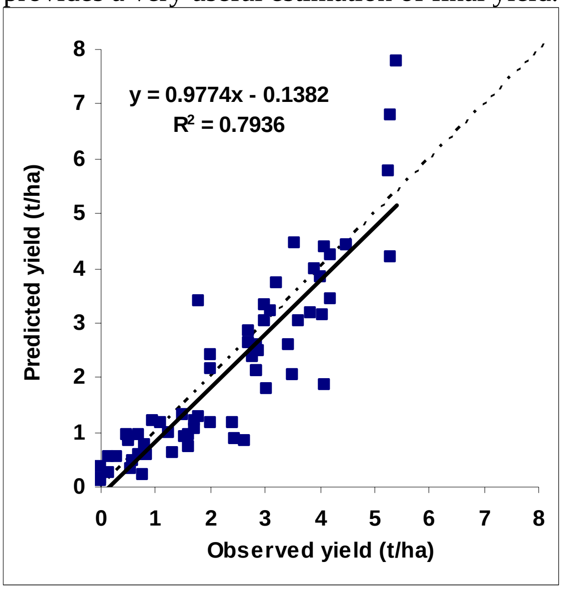

Figure 1. Observed and simulated wheat grain yield for paddocks using Yield Prophet in 2005 and 2006 (n=64, RMSD=0.78t/ha). The dashed line indicates the ideal 1:1 relationship. (Sourced from Hunt et al. 2006)

The farming system model APSIM (Keating et al. 2003) has been applied to many management issues across the northern, southern and western grains belt. In southern Australia the application of APSIM has contributed to a rethink of the value of stored soil water, confirmed the value of early planting and highlighted the importance of the 'bucket size' or water that is available to the root-zone. Chapman et al. (2002) working in the northern grains belt, used cluster analysis on the output of the sorghum model in APSIM to identify mid season, mild terminal and severe terminal droughts. They applied this data to trials comparing different sorghum hybrids. Agronomists in the southern grains belt are aware that most crops most years suffer moisture stress. However, there are a range of ways that the crop is stressed with intermittent or transient droughts, seasons that start poorly and stay dry and seasons that start well and end in terminal drought. In the following sections of the paper we use APSIM to investigate season types for wheat in South Australia and relate ENSO to both season type and regional rainfall. Neither climate science nor simulation modelling will predict a future outcome, but they may be able to assist in quantifying an uncertain future with risk profiles for different decisions. A better characterisation of the season will also provide a more robust explanation of the recent past.

Methods

An investigation of the impact of ENSO on rainfall and season type requires a list of years when the Pacific Ocean was in El Nino, La Nina and Neutral phases, a time series of rainfall, simulated moisture stress and simulated wheat yield. El Nino and La Nina years were taken from the Bureau of Meteorology 23 El Nino years [1911 13 14 19 25 40 41 46 52 53 59 65 69 72 77 82 87 91 93 94 97 2002, 06], 20 La Nina years [1909 10 16 17 24 28 38 50 55 58 64 70 71 73 74 75 88 96 98 2007] and 58 Neutral years in the period from 1907 to 2007.

Rainfall data for the southern grains belt is available from the Bureau of Meteorology website. We selected time series of growing season rainfall (April to October) from two regions; the south east region as defined by the Bureau of Meteorology (south of a line from about Dubbo to the top of the Eyre Peninsula) and the South Australian agricultural region (south of a line from upper Eyre Peninsula to the Victorian border 134.50:140.50E, 32.50: 36.50S). On Figure 2 this is equivalent to a line slightly north of Minnipa and Orroroo across to the Victorian border. Figure 2 also shows the eight sites that were used for APSIM runs and Table 2 shows the average, maximum and minimum growing season rainfall (April to October) for each site.

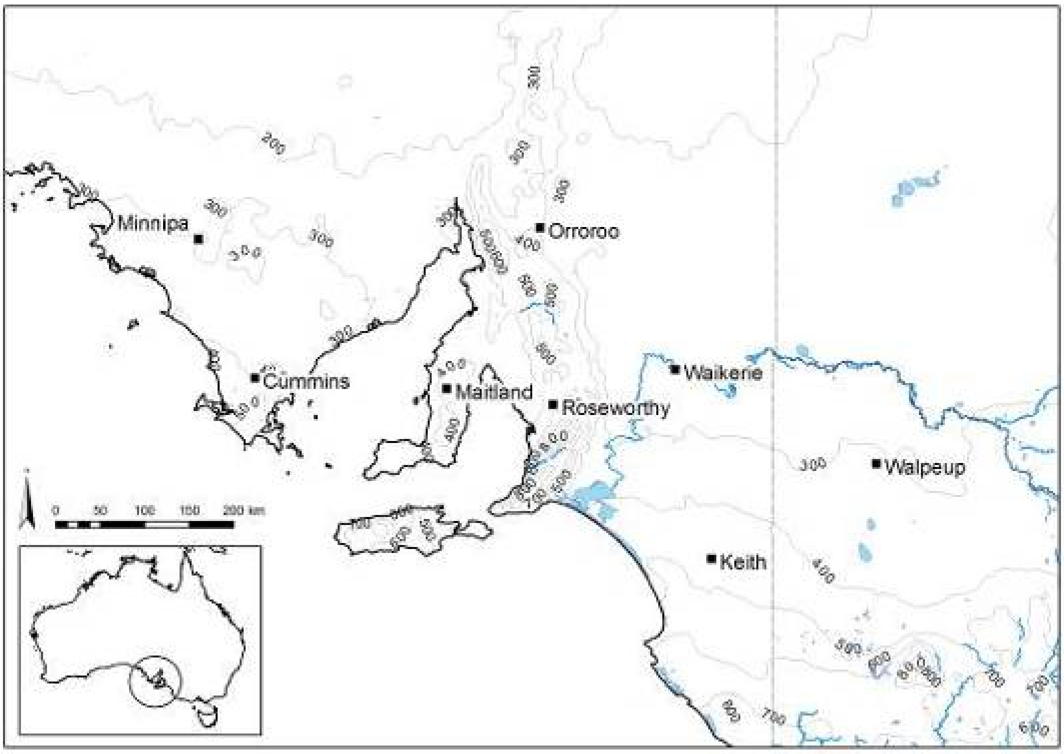

Figure 2 Map showing annual rainfall isohyets and eight locations used in this study.

Global Issues Paddock Action. Proceedings of the 14th Australian Agronomy Conference. September 2008, Adelaide South Australia.

Table 2: Annual rainfall and the range of growing season rainfall (GSR) for each of the sites.

Rainfall Zone	Site	Annual rainfall (mm)	Average GSR (mm)	Min GSR (mm) (year)	Max GSR (mm) (year)
Low	Waikerie	257	165	51 (1982)	329 (1974)
	Walpeup	336	220	65 (1982)	442 (1956)
	Orroroo	336	225	77 (1982)	406 (1974)
	Minnipa	340	254	99 (1982)	506 (1956)
High	Cummins	425	343	146 (1959)	574 (1956)
	Roseworthy	447	334	120 (1914)	583 (1923)
	Keith	463	343	146 (2006)	519 (1956)
	Maitland	500	382	169 (1959)	670 (1916)

Time series of simulated yields for APSIM were based on daily meteorological records sourced from the SILO database (Jeffrey et al. 2001). Simulations were designed so that the effect of individual growing season conditions on the growth of wheat were captured and there were no effects of fallow or previous seasons performance on the simulated wheat crop. The management logic therefore includes a number of assumptions: Soil water, soil nitrogen and surface organic matter were reset on May 14 each year. At this reset, soil water was initialised to a total of 30mm relative to the wheat lower limits. This constitutes 26 % of maximum available soil water for the grey brown cracking clay used in all simulations. Soil mineral N was initialised 45 kg/ha distributed in the top 5 soil layers. Surface organic matter (wheat residue) was initialised to 1000 kg/ha and soil organic C was set to 2 % (0-10 cm). Each year on May 15, wheat (cv. Yitpi) was sown (180 plants/m^2) with 50 kg/ha N as urea. The same rate of N was applied at Zadok stage 31 to reduce the likelihood that N was a limiting factor in crop growth. Grain was harvested when the crop was mature.

The soil chosen for use in the simulation study is a grey brown cracking clay (brown vertosol) common to the higher rainfall regions of south east SA and field measured at a location near Bordertown, SA. It has a high organic carbon content (2 %, 0-10 cm) and a rooting depth of about 120 cm. The plant available water capacity is 154 mm. This soil has a higher water holding capacity than most soils in South Australia, we also used a lighter textured soil with a lower water holding capacity and results were broadly similar (data not shown).

Similar to Chapman et al. (2002) the soil water deficit factor for photosynthesis (swdef_photo) was output for each 100°C days of the crop growth period and this was used as the indicator of crop water stress. The soil water deficit factor is calculated from the ratio of actual soil water supply to the potential soil water supply. A stress factor of 1 indicates no stress, and 0 indicates complete stress. Crop failures and early maturation occurred in a small number (< 2%) of simulated cropping years which were removed from further analyses.

The crop water stress parameter is not used to determine the simulated yield in the APSIM-Wheat model. The model simulates the growth and development of a wheat crop in a daily time-step on an area basis in response to weather (radiation, temperature), soil water and soil nitrogen. The model simulates phenological development, leaf area growth, biomass and N concentration of leaves, stems, roots and grains. Grain number is determined by the amount of stem biomass at anthesis (25 grains/gram of stem). During the grain filling stage, daily growth is partitioned initially to grain fill. If grain fill demand exceeds total daily supply, up to 20% of stem biomass may be translocated. In effect, the size of the canopy at anthesis can have a large effect on grain fill and yield as potential grain fill is limited by low water uptake and N. Yield is therefore influenced by pre-anthesis stress - this contributes to both grain number, and also influences susceptibility to stress later in the season, which also influences grain size.

Outputs from the APSIM runs of the low and high rainfall sites were grouped separately for cluster analysis using methods contained in the R statistical library (R Development Core Team, 2008). Firstly, an euclidean distance matrix was created from the stress values over the life of the crop. A hierarchical clustering function (hclust) was applied to the squared distance matrix to group the runs based on Ward's minimum variance method. Examination of the resulting dendrograms showed good separation into 3 clusters for the high rainfall zone and good separation at the 4 cluster level for the low rainfall zone. The analyses of seasonal stress patterns presented below are based on those cluster groupings.

Results

The time series in Figure 3 shows annual growing season rainfall as a percentile rank for South Eastern Australia (3a) and South Australian agricultural (3b) regions. It is clear from these figures that recent years have been dry and that it is some time since there has been a decile 8 or wetter winter. It is difficult to see any strong trend in rainfall, obviously the 50s and 70s were wetter decades than the recent two decades, but the 30s were also dry. Although far from perfect, the impact of ENSO is evident with more of the very dry years being El Nino years and more of the wetter years being La Nina years than would be expected by chance. Most, but not all, El Nino years are below the median (decile 5 or drier). The 1994, 2002 and 2006 droughts were related to El Nino. The 2007 late developing La Nina was unusually dry and this was possibly due to the positive Indian Ocean Dipole. The chance of being in the lowest tercile, middle or wettest tercile in the El Nino and La Nina years is shown in Figure 4 for SE Australia (4a) and for the South Australian agricultural region (4b). The swings in the probabilities are greater for the wider SE Australian region than for South Australia, nevertheless the chance of being in the bottom tercile is more than doubled in an El Nino year and in La Nina years the chance of being in the top tercile has increased from 33% to 50%, Figure 5 shows the monthly rainfall for 4 locations in the medium to high rainfall zone and 4 locations in the low rainfall zones of the cereal belt in South Australia and western Victoria. This shows the strong winter dominance of rainfall in Mediterranean climates especially in the western sites. Figure 5 also shows the average of the 23 El Nino events and the average of the 21 La Nina events for each site, the general impact of El Nino is to reduce the winter maximum and La Nina generally accentuates the winter maximum. There is little impact of ENSO on summer or early autumn rainfall.

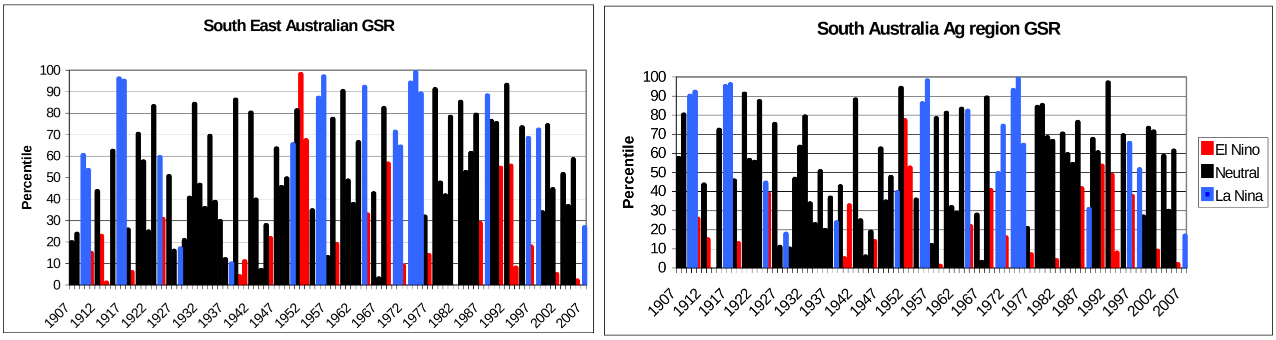

Figure 3 percentile of growing season rainfall for (a) South Eastern Australia, (b) South Australian agricultural region.

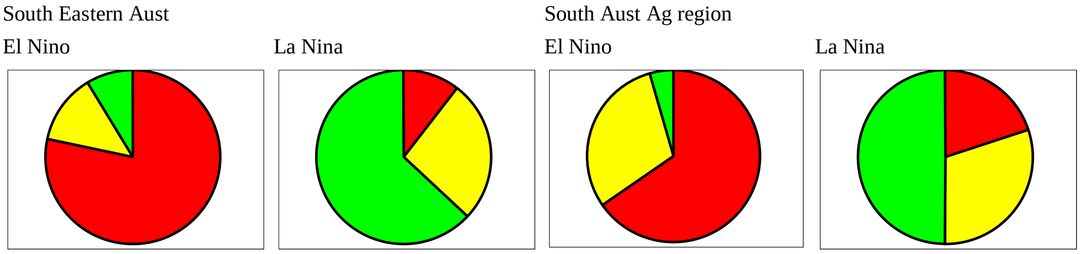

Figure 4. Probability of being drier than long term 33rd percentile (red) or wetter than 67th percentile (green) in El Nino and La Nina years in South Eastern Australia (4a) and South Australian Agricultural region (4b)

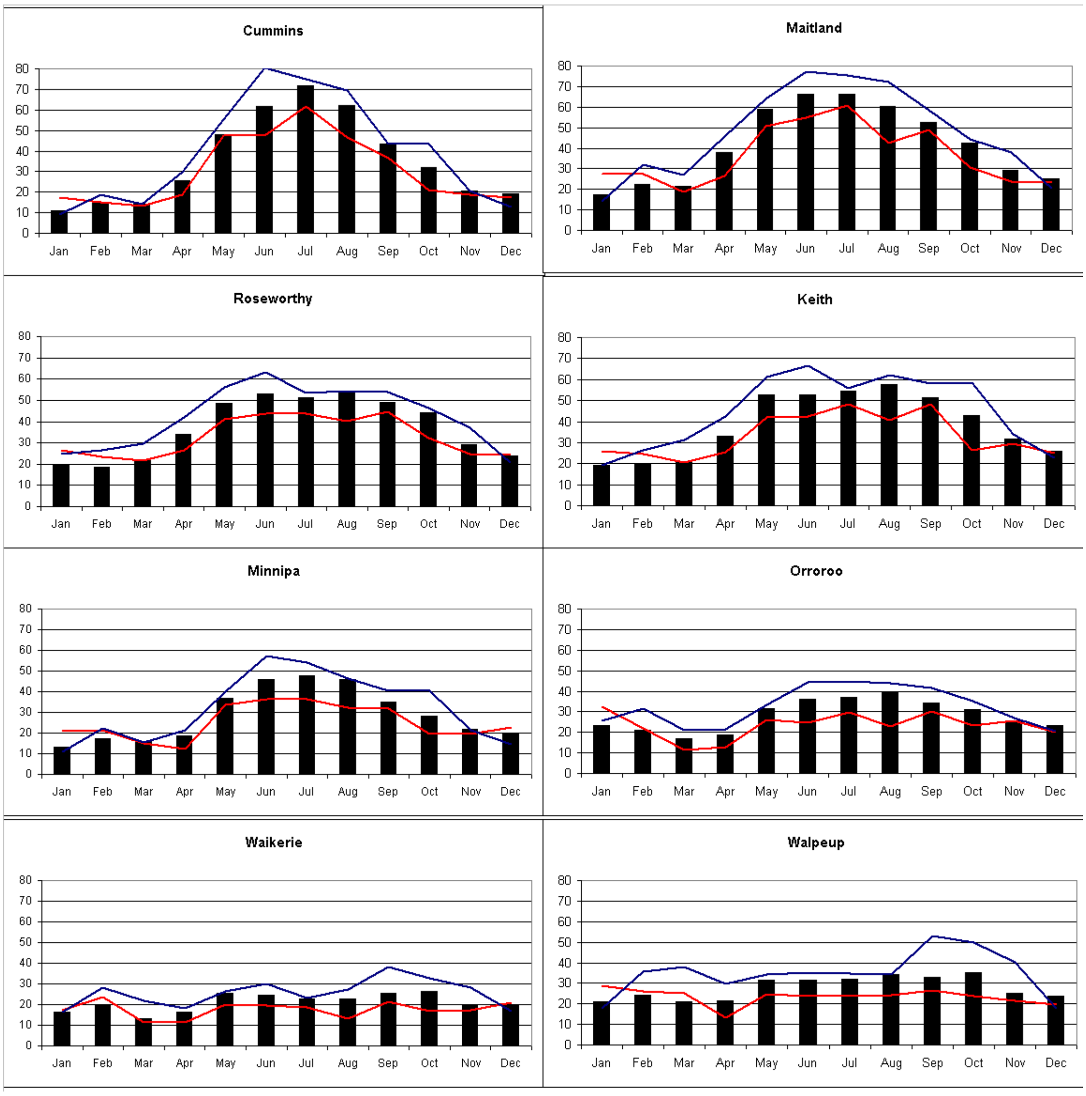

Figure 5. Average monthly rainfall; All years in record (columns), El Nino years (red line) La Nina years (blue line).

Classification of patterns of season types

The cluster analysis for the low rainfall locations indicate that there are 4 season types which we have defined as the pattern of stress from 0 to 600 degree days (equivalent to emergence to end of juvenile stage, or Zadocks growth stages 0 to 32) and 600 to 1200 degree days (equivalent to the end of juvenile stage to the end of flowering/start of grain fill or Zadocks stages 32 to 71): early low stress followed by low stress (L-L); early high stress followed by low stress (H-L); early low stress followed by high stress (L-H); and early high stress followed by high stress (H-H). The average stress for these four season types is shown in Figure 6. Because the simulations had a fixed sowing date the time of the year that the stress occurred was similar for each case.

Table 3 shows the frequency of each season type and average yield for the four sites. At Minnipa, Orroroo and Walpeup, the L-H season type occurs the most frequently (39-42 % of seasons). At Waikerie, the H-L season type had the highest incidence (50 % of seasons) and the lowest average grain yield followed by the H-H season type (34 % of seasons). At all sites, grain yields were highest in the seasons with the lowest stress (L-L) followed by L-H. The differences in average grain yield between the H-L and H-H season types were not large (although the 10th percentile for the H-L seasons types was always much higher than that of the H-H, indicating that in 10 % of seasons falling into the H-L category, grain yield could be high).

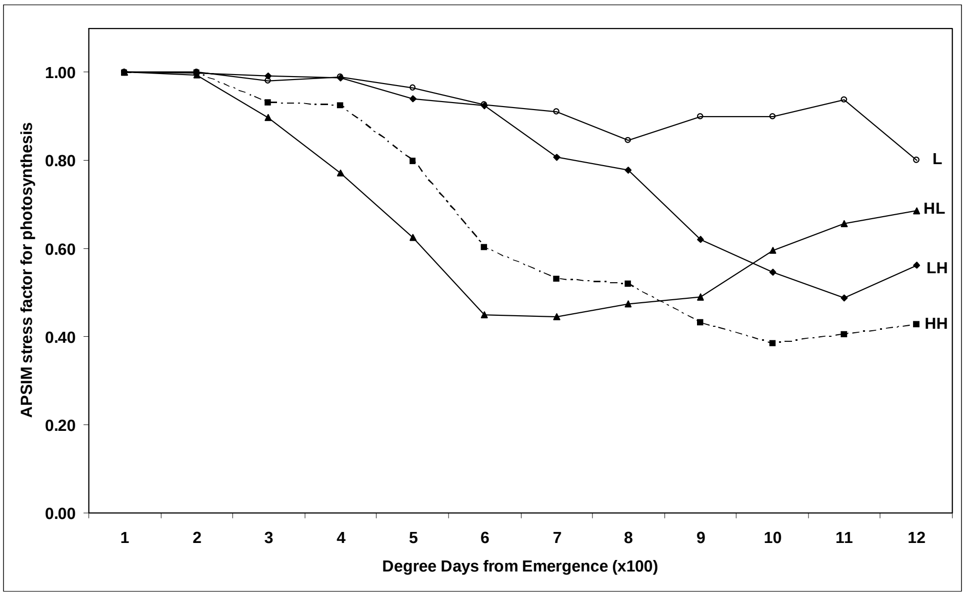

Figure 6. The pattern of stress defined by the cluster analyses from all low rainfall locations and seasons (1906-2007).

Table 3. Average grain yield (t/ha) and the percentage of crops between 1906 and 2007 occurring in each season type.

Met	L-L	L-H	H-L	H-H
Minnipa	3.8 (25%)	3.1 (42%)	1.7 (19%)	1.6 (15%)
Orroroo	3.7 (13%)	3.1 (39%)	1.5 (21%)	1.4 (28%)
Waikerie	3.8 (1%)	2.5 (15%)	1.0 (50%)	1.4 (34%)
Walpeup	3.6 (15%)	2.7 (41%)	1.7 (19%)	1.3 (26%)

The cluster analysis for the high rainfall locations indicate that there were 3 season types as shown in Figure 7. These were early low stress followed by low stress (L-L); early low stress followed by high stress (L-H); and early high stress followed by high stress (H-H). The H-L season type was not identified by the cluster analysis as a distinct group.

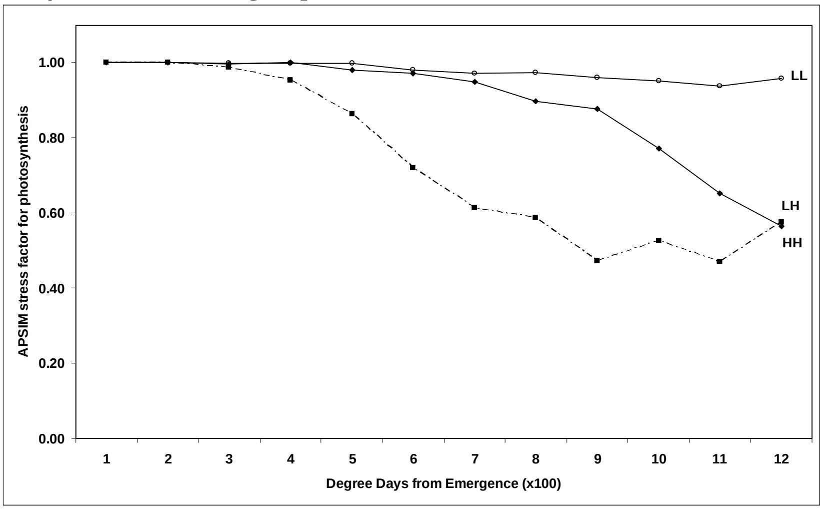

Figure 7. The pattern of stress defined by the cluster analyses from all high rainfall locations and seasons (1906-2007).

At the high rainfall locations, the majority of seasons (52 to 74 %) fell into the L-L season type followed by the L-H (19-30%) with grain yield being similar in these groupings (Table 2). The H-H season type occurred most frequently at Roseworthy and least often at Maitland, which is considered a favoured environment. The grain yield in the L-L season types might be expected to be higher and this is most likely due to nitrogen limits in the better seasons when potential yield is exceeding 4 t/ha.

Table 2. Average grain yield (t/ha) and the percentage of crops between 1906 and 2007 occurring in each season type.

Location	L-L	L-H	H-H
Cummins	3.7 (66%)	3.6 (24%)	2.0 (10%)
Keith	3.8 (60%)	3.7 (29%)	1.9 (11%)
Maitland	3.8 (74%)	3.8 (19%)	2.3 (7%)
Roseworthy	3.8 (52%)	3.6 (30%)	2.2 (18%)

Figure 8 shows the number of El Nino and La Nina years in each season type for low and medium to high rainfall sites. There was no strong pattern with neutral years (not shown). If there was no relationship between ENSO and season type the ratio of El Nino to La Nina would be close to 1:1 as there were 23 El Nino and 20 La Nina events in the historical record. The season type with low stress (LL) has many more La Nina years and few El Nino years. In the medium to high rainfall sites although La Nina dominate the low stress years there are a number of El Nino years. If an El Nino related drought causes shortages on the domestic grain market, these years of low stress in El Nino years in higher rainfall areas can be very profitable. The season types HL and HH has many more El Nino years than La Nina years, especially in the high rainfall zone. Hence a forecast of El Nino should be associated with an increased chance of moisture stress rather than a categorical forecast of a drought. If a serious drought is considered as a 1 in 10 or 1 in 20 event, and there have been 23 El Nino events in the last 100 years, clearly there will be more El Nino events than bad droughts. The analysis with rainfall shown in Figures 3 and 4, and the relative number of El Nino and La Nina years in each drought type shows how ENSO tips the odds rather than providing guarantees.

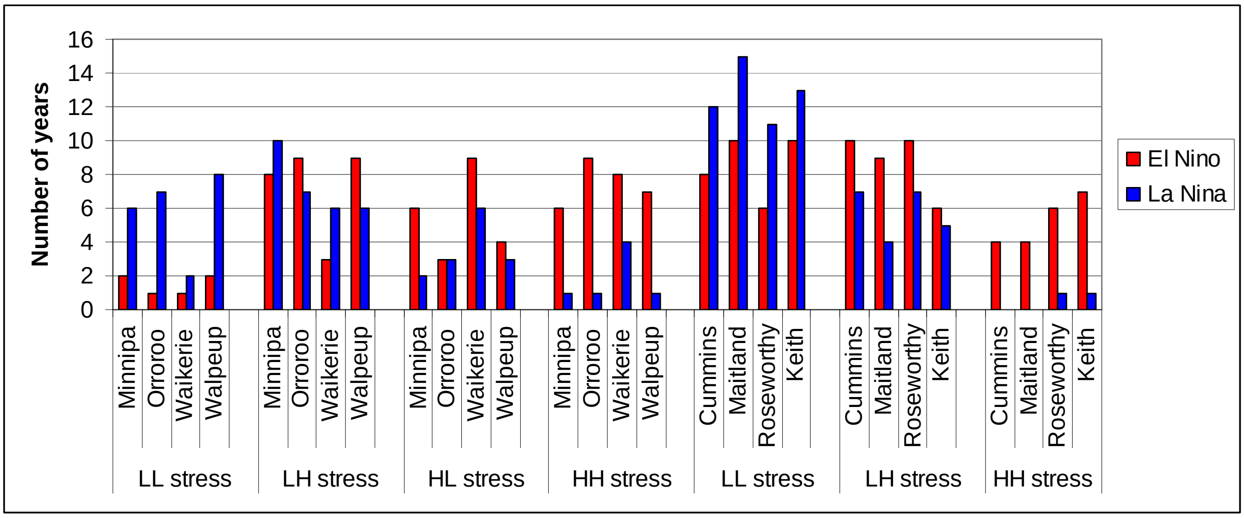

Figure 9 Frequency of El Nino and La Nina years in season types for each location (note Neutral years not shown)

Concluding remarks

Thinking clearly about risk is not easy. Access to excellent historical climate records in Australia is an asset that helps quantify the main driver of production risk. It is underutilising the richness of the daily rainfall records recorded over a century to just summarise a location as "15 inch rainfall country" or even to summarise the past season by the growing season rainfall. The use of APSIM to categorise the nature of stress in the season helps to put the results from a series of field trials in context. A watching brief on the performance of dynamic models, the application of Indian Ocean Dipole and the Southern Annular mode should not exclude including ENSO in risk management decisions.

As mentioned earlier, accepting a non-stationary climate has implications. Writing about the costs of climate change Quiggin and Horowitz (2001) observed *"The information held by economic actors about the climate becomes more diffuse, and hence less valuable in the presence of a new source of uncertainty. Thus climate change may be regarded as destroying information. This information may in some cases be represented by formal probability distributions of temperature and rainfall derived from historical records. More frequently, it is the informal knowledge of particular local climates that is acquired by attentive individuals over a long period."* The notion of destroying information may be too strong, nevertheless, information held by farmers and agronomists is eroded by climate change. We believe that simulation models and a better working knowledge of climate drivers are part of the toolkit for agronomists as they work with farmers to manage risk in a variable and non-stationary climate.

How might these tools be used ?

To adjust plans for the future. When the Bureau of Meteorology suggests that there is an increased chance of El Nino, it is worthwhile for agronomists in southern Australia taking note, providing they realise that El Nino increases the odds of a poor season rather than providing a guarantee. Using simulation modelling of crop yields to put the impact of ENSO and other climate drivers in context with stored soil water and sowing time will provide a more complete risk profile. The level of accuracy from ENSO and other climate drivers such as IOD, and even accurate measures of starting soil water is likely to only be appropriate to adjust plans, never be the sole basis for planning.

To contribute to interpreting the recent past. In addition to using simulation modelling and climate science for planning, we argue that these tools have a role to play in putting farmers paddocks and field trials into context. It is worth noting that 2002 and 2006 were El Nino years and the dry spring of 2004 was associated with a negative SOI. It is important to also note that the very poor outcome of 2007 cannot be explained by ENSO and that the Indian Ocean Dipole provides some insights. Simulation modelling can rank the last season and the run of recent seasons against the long term climate record. A contribution of this study is an objective way to categorise the last season in terms of the timing of the stress.

Simulation modelling and climate science are part of the tool kit and cannot substitute field trials and observation of farmer practices. In many cases they can confirm and quantify what is known about the last season, however it is when they differ that learning is most likely.

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