Can we use forecasts of El Ni?o and La Ni?a for frost management in the Eastern and Southern grains belt?

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Abstract

Frost damage on winter cereals in Australia is a low frequency but high consequence threshold event with losses up to 100%. In frost prone regions grain growers delay their planting time and adjust the variety maturity selection to minimise the risk of severe frost damage and in doing so they usually incur a yield penalty of 5% to 20%. This trade-off between sowing wheat crops early enough to gain the yield advantage of milder spring conditions at grain fill, but late enough to avoid frost at flowering has long been recognised. Managing this trade-off is difficult because the date of the last frost is highly variable, hence the interest in guidance on the risk for the coming season. There is good reason to expect greater frost risk with the clear night sky associated with El Ni?o years and less frost risk in La Ni?a years. This raises the question as to whether information on the likelihood of a season being El Ni?o or La Ni?a should be used to adjust planting time and maturity type.

We found that frosts are more frequent and the median date of the last frost is later in El Ni?o years, whereas in a La Ni?a year there are fewer frosts and the median date of the last frost is generally earlier. However, the question most grain farmers are interested in is not the number of frosts, or even the median date of the last frost, but the timing of the latest 10-20% of frosts. Unfortunately we found that there was no distinction for this parameter using perfect knowledge of El Ni?o or La Ni?a. This suggests caution is warranted when basing frost risk management on imperfect forecasts of the El Ni?o Southern Oscillation (ENSO) index.

Key Words

Frost risk, seasonal climate forecasts, El Ni?o Southern Oscillation

Introduction

Frost at the time of flowering (anthesis) and grain filling of wheat is a significant risk across much of the Australian grains belt (Single 1975; Stone et al. 1996; Rebbeck et al. 2007). Spring provides the best combination of moisture and temperature for anthesis and grain filling. Although spring conditions are usually warm in southern Australia, there are occasional but damaging radiation frosts associated with slow moving high pressure cells preceded by a cold spell that brings in air that is not only cold but also very dry (dew point less than 2.2^{o}C).

Although rainfall is the most common atmospheric element related to the El Ni?o Southern Oscillation (ENSO), temperature is also influenced by ENSO (Jones and Trewin 1999). Stone et al. (1996) showed that minimum temperatures in spring associated with frost could be predicted using the 5-phase Southern Oscillation Index system (Stone and Auliciems 1992). Willcocks and Stone (2000) conducted a comprehensive analysis of the influence of the southern oscillation on frost risk for 12 sites ranging from Biloela in central Queensland to Dubbo in central NSW. Anwar et al. (2007) analysed a range of sites in south eastern Australia and found that the date of last frost tended to occur later in the year during the negative SOI years, and earlier during the positive SOI years. However they could not find a statistically significant relationship using the SOI five phase system as a predictor. They noted that the relatively small number of years in each phase made it difficult to find a statistically significant relationship.

Grain farmers in frost prone areas of Australia have long used sowing time and varieties with a range of maturities to balance the risk of yield loss from spring frost on one hand, and rising temperatures with

declining soil water during grain filling on the other. This trade-off was clearly described over 30 years ago by Single (1975); it is found in most text book descriptions of Australian grain production and is modelled directly in decision support systems such as WHEATMAN (Woodruff 1992) and indirectly in models such as APSIM (McCown et al. 1996).

Unlike horticultural enterprises where growers have management options such as wind machines or irrigation that can make use of a forecast of frost a few days ahead or even respond to a critical temperature, grain farmers need guidance at sowing in April or May for frost events in September to October. In autumn the Australian Bureau of Meteorology provides a comprehensive summary on the likelihood of an El Ni?o or La Ni?a developing over the coming season (http://www.bom.gov.au/climate/enso). Although the ability to predict future ENSO states is far from perfect, a number of growers and advisers in southern Australia have asked whether this information could be used for managing frost risk. In this paper we investigated whether there is any influence from ENSO on the risk of frost for a number of locations in the Australian grains belt.

Methods

Historical daily minimum temperatures were obtained from seven sites in the grains belt associated with the CLIMARC project which digitised daily temperature back to 1900 (Raynor et al. 2004). Data from 1900 to 2005 was analysed for seven stations across eastern and south-eastern Australia: Goondiwindi (Qld); Gunnedah, Wagga Wagga and Deniliquin (NSW); Mildura and Nhill (Vic); and Snowtown (SA). The Bureau of Meteorology's classification of El Ni?o and La Ni?a years has been used which leads to 24 El Ni?o years [1902 05 11 13 14 19 25 40 41 46 52 53 59 65 69 72 77 82 87 91 93 94 97 2002], 21 La Ni?a years [1903 06 09 10 16 17 24 28 38 50 55 58 64 70 71 73 74 75 88 96 98] and 61 Neutral years in the 106-year record.

The relationship between the temperature recorded in the Stevenson screen and frost damage in a wheat crop is complex. Not only is minimum temperature very sensitive to local topography and complex cold air drainage, during a radiation frost the surface of the crop becomes the radiating surface. In the decision support system WHEATMAN, the temperature at head height is assumed to be 3.5?C colder than the Stevenson screen (Woodruff 1992). A conservative approach is to use 2?C in the Stevenson screen as the threshold below which there is a risk of frost damage. For this paper we conducted the same analysis with 0°C but present the results for the threshold of 2?C.

Table 1 shows that the number of nights below 2?C has decreased over the 100 year period at Goondiwindi, Gunnedah and Mildura but there is no significant linear trend for the more southern sites. When we removed the trends in the number of frosts and repeated the analysis of the impact of ENSO on nights below 2°C there were no substantial changes to our hypothesis testing.

Table 1. The average number of frosts per year (chance of <2?C at Stevenson screen) for locations as categorised by an El Ni?o (EN), La Ni?a (LN) and Neutral (N) year, from 1900 – 2005. Brackets indicate the percent departure from "All years". The trend in the number of frosts per year is shown in terms of the linear regression slope and the Pearson correlation coefficient for locations that are significant at the 0.05 level or better. The p values below the number of frosts are for a one-tailed t-test comparing that column against the other two columns (eg El Ni?o against all non El Ni?o years which is the sum of La Ni?a and Neutral years).

				Average number of frosts			
Location	**Latitude**	**Longitude**	**Trend**	**All yrs**	**EN**	**LN**	**N**

Goondiwindi	-28.55	150.31	Slope = -0.08 r = 0.25; p<0.01	18	23 (+28%) p<0.005	15 (-17%) p<0.10	17 (-6%) n.s.
Gunnedah	-30.98	150.25	Slope = -0.25 r = 0.51; p<0.001	35	41 (+17%) p<0.01	27 (-23%) p<0.01	35 (0%) n.s.
Wagga	-35.13	147.37	n.a.	40	47 (+18%) p<0.005	34 (-15%) p<0.01	40 (0%) n.s.
Deniliquin	-35.53	144.95	n.a.	25	30 (+20%) p<0.01	19 (-24%) p<0.01	24 (-4%) n.s.
Mildura	-34.18	142.2	Slope = -0.08 r = 0.2; p<0.05	15	17 (+13%) n.s.	13 (-13%) n.s.	14 (-7%) n.s.
Nhill	-36.33	141.64	n.a.	35	46 (+31%) p<0.005	30 (-14%) p=0.11	33 (-6%) p<0.10
Snowtown	-33.78	138.21	n.a.	17	20 (+18%) p<0.05	14 (-18%) p<0.10	16 (-6%) n.s.

Results and Discussion

The trend towards fewer frosts at some locations needs to be considered as part of risk management but is not the focus of this study on ENSO and frost. As expected from basic climate principles, there are generally more frosts in El Ni?o years (average increase of 20%) and fewer frosts in La Ni?a years (average decrease of 18%). With the exception of Mildura, the shift in the number of frosts with ENSO is statistically significant.

Although the number of frosts through the season is of interest and frosts will check the vegetative growth of wheat, frosts in winter months have a minimal impact compared to late spring frosts. In terms of risk management, it is the last frost that is the key event to be avoided. Figure 1 shows the probability distribution of the last frost for the seven sites for El Ni?o years, La Ni?a years and neutral years. The range of dates of the latest frost is extremely wide, with the 10th to 90th percentile in the order of 6 weeks apart. This range highlights the difficulty of managing this risk and explains why growers and advisers are keen for any tool that narrows the range of possible outcomes.

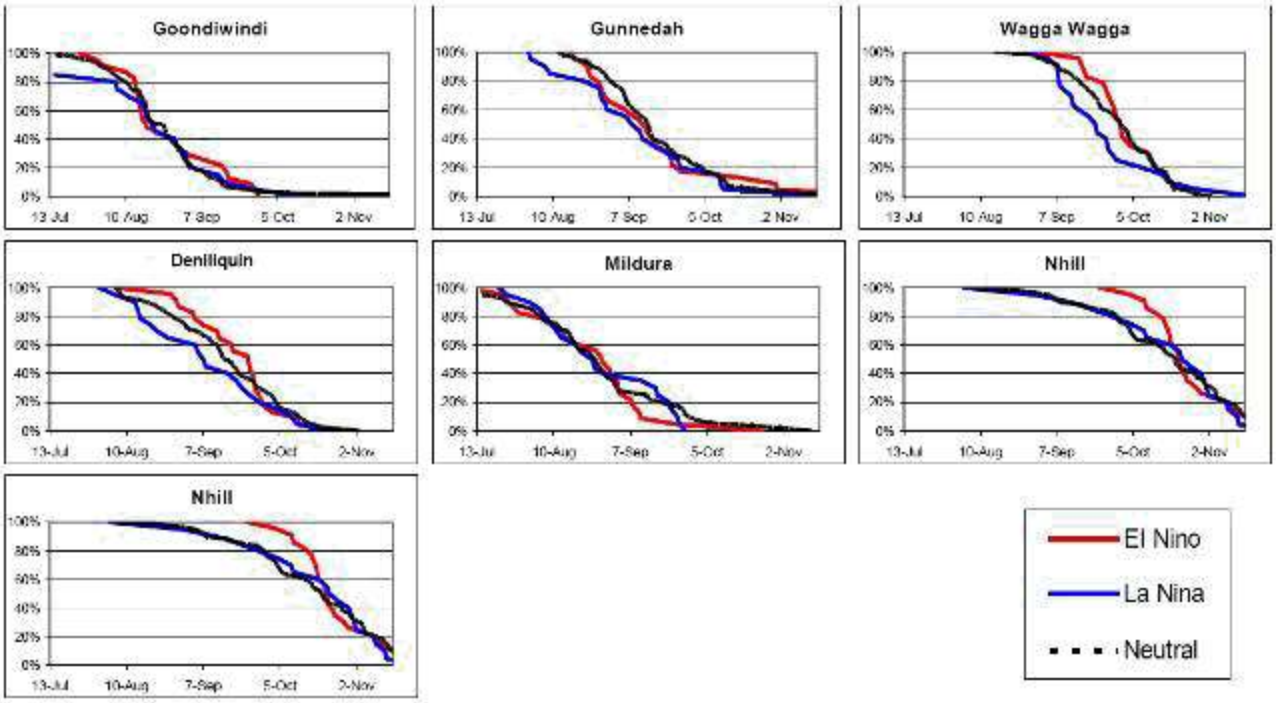

Figure 1. Probability of minimum temperature of 2?C or less occurring later than given date for 24 El Ni?o years, 21 La Ni?a years and 61 neutral years between 1900 to 2005 for a range of locations in the Eastern and Southern grains belt.

Figure 1 shows that for most sites the last frost tends to be later in El Ni?o years and earlier in La Ni?a years. However while this is true for most of the distribution, there is little discrimination for the latest 20% of frosts. At Mildura, El Ni?o years seem to be associated with earlier frosts, but this result is most likely noise in the relationship. Analysis using a threshold of 0?C shows a similar pattern with a tendency toward earlier last frosts in La Ni?a years and later in El Ni?o years but with no clear distinction in the last 20% of the distribution.

Unfortunately growers are less interested in the number of frosts or even the median date of the last frost, as it is the latest 20% of frosts that would be most valuable to forecast. In all the sites examined, the tail of the distribution seems to be relatively insensitive to El Ni?o or La Ni?a conditions. When presented with this finding some farmers have suggested that later in spring, even in La Ni?a years, there is less moisture available and if the right synoptic events occur, the minimum temperature can fall suddenly. Whatever is the cause of such an anomaly, this analysis suggests that extreme caution should be used by farmers, especially if they consider taking extra risk with frost on the basis that a La Ni?a is more likely (or even that an El Ni?o is less likely).

Risk is commonly defined as the product of frequency and consequence. Using this framework a 2 week delay in sowing, resulting a yield loss of 10% each year, would be equivalent to a total crop loss 1 year in 10. In the general context of risk in business planning, Williams (1996) warned against the simple ranking of risks in this way because high consequence, low frequency events are inherently difficult to manage. Typically, these are the events for which we seek insurance. Taleb (2007) noted that these high consequence, low frequency events are difficult for experts to forecast and for decision makers to model. Using probabilistic ENSO based forecasts of spring rainfall to decide on nitrogen rates is challenging, especially when a minority outcome occurs (e.g. an increased probability of a wet season is forecast but it turns dry). However this mis-forecast is rarely catastrophic. In contrast, sowing a significant area of a farm early on the basis that there is a reduced chance of late frosts will have major consequences if the minority outcome occurs. If any forecast is to be used to adjust sowing time, it would be prudent to still spread the risk of frost by having a range of flowering times. A further complication to using a forecast of

El Ni?o to change sowing dates is that a decision to delay sowing/flowering for frost avoidance could lead to yield loss associated with the drier than usual spring.

Conclusion

At the study sites investigated, it was found that frosts are more frequent and the median date of the latest frost is often later in El Ni?o years, whereas in a La Ni?a year there are fewer frosts. However, the main interest of grain farmers is not the number of frosts, or even the median date of the last frost, but the timing of the latest 10-20% of frosts. Unfortunately we found that there was little difference in this parameter, and therefore suggest that extreme caution should be used in applying a prediction of future ENSO states for managing frost risk.

References

Anwar M, Rodriguez D, Liu DL and Power SB (2007) Quantification of the accuracy of forecasting tools for rainfall and minimum temperatures in south eastern Australia. Report to GRDC on project DAV00006, Tools to reduce the impact of climate variability in SE Australia.

Jones DA and Trewin BC (2000) On the relationships between ENSO and Australian land surface temperature. *Int. J. Climatology* 20:697-719.

McCown RL, Hammer GL, Hargreaves JN, Holzworth DN and Freebairn DM (1996) APSIM: A novel software system for model development, model testing and simulation in agricultrual systems research. *Agricultural Systems* 50: 255-71.

Rayner DP, Moodie KB, Beswick AR, Clarkson NM and Hutchinson RL (2004), New Australian daily historical climate surfaces using CLIMARC. Queensland Department of Natural Resources, Mines and Energy.

Rebbeck M and Knell G (2007). Managing Frost Risk. A guide for Southern Australian grains. SARDI and GRDC.

Single WV (1975) Frost Injury. In Australian Field Crops Vol 1, Wheat and other temperate cereals. eds Lazenby A and Matheson EM. Angus and Roberston, Sydney pp364-83

Stone RC and Auliciems A. (1992). SOI phase relationship with rainfall in eastern Australia. *Int. J. Climatology* 12: 625-36.

Stone RC, Nicholls N and Hammer GL (1996). Frost in NE Australia: trends and influences of the Southern Oscillation Index. *Journal of Climate* 9, 1896-1909.

Taleb NN (2007) The black swan: the impact of the highly improbable. Random House, New York.

Willcocks J and Stone RC (2000) Frost risk in eastern Australia and the influence of the Southern Oscillation. Queensland Centre for Climate Application QI 0001.

Williams TM (1996) The two dimensionality of project risk. *International Journal of Project Management* 14:185-186.

Woodruff DR (1992) 'WHEATMAN' a decision support system for wheat management in sub-tropical Australia. *Australian Journal of Agricultural Research* 43: 1483-99.