Spatial modelling of extreme temperatures in the southern mallee of Victoria

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Abstract

Extreme temperatures around anthesis of wheat have the potential to reduce grain yield. However, at paddock level their impact can be expected to be highly spatially variable due to topographic features. In this study we develop simple algorithms to spatially model the existing variability in extreme temperatures at paddock level in order to identify areas of high risk of extreme temperatures around the time of the anthesis of wheat. Twenty-five tinytag data loggers were installed at 0.8m height to represent crop head height across a 164.3 ha paddock at Birchip in the southern mallee of Victoria, to spatially record the daily course of temperatures around the average date of anthesis in the region. Multiple linear regression analysis techniques were used to build models relating extreme temperatures to topographic features of the paddock i.e. elevation, aspect, slope and maximum and minimum temperatures at the farm. During calibration the developed model explained up to 94% and 95% of the observed variability in maximum and minimum temperatures, respectively. Elevation was negatively correlated with the observed maximum and minimum temperatures whereas aspect was correlated positively with the maximum temperatures and negatively with the minimum temperatures. Slope was correlated negatively with the maximum temperatures and positively with the minimum temperatures. During validation the developed equations explained up to 85% and 95% of the observed variability in maximum and minimum temperatures, respectively. We concluded that the temperature variation within the paddock can be explained by the variation in its topographic features.

Media summary

The spatial variation in extreme temperatures at paddock level can be described using topographical features of the landscape.

Key words

Frost, heat stress, modelling, spatial variability.

Introduction

Exposure to low temperatures during anthesis of wheat can reduce grain yields through the production of infertile florets and frost damage. Production of infertile florets has been observed even at temperatures as high as 9.5?C during a few days around anthesis (Slafer and Slavin, 1991; Russell and Wilson, 1994). Similarly, temperatures above 31?C immediately before anthesis have the potential to reduce grain yield by inducing pollen sterility, thus reducing grain numbers (Wheeler et al., 1996).

Rainfall variability and frost damage are the major sources of yield fluctuation in dryland crops in south-eastern Australia. Regional yield losses due to frost can vary from 5 to 35% in New South Wales and from 5 to 50% in Victoria, depending on severity and timing (Cawood, 1996).

Variations in topography alter the energy balance of the landscape by affecting interception of radiation and modifying the speed and direction of airflow across the surface. Soil type also affects land temperature (Cawood, 1996). Differences in height of only one metre can allow cold air drainage down slopes and the formation of the frost pockets. In the southern hemisphere, northerly facing slopes will store more energy during the day and are likely to maintain warmer temperatures at night. The areas of coldest temperature are generally associated with low-lying plains. Depressions usually have the lowest extreme temperatures because of the formation of cool-air drainage pools and poor air circulation (Cawood, 1996).

Lookingbill et al. (2003) indicated that, apart from elevation, some other topographical parameters like relative slope position, distance from a stream, aspect and potential relative radiation also affect the spatial variability of extreme temperatures in any particular paddock.

The objectives of this work were:

- to test the hypothesis that the spatial variation in extreme temperatures at paddock level can be predicted
- from the elevation, aspect and slope within the field
- to develop a simple model to predict the spatial variability in extreme temperatures at paddock level.

Materials and Methods

Study area

The area under study was a 164.3 ha paddock on a farm at Birchip in the southern mallee of Victoria, with considerable variation in topography.

Setup, data collection and methodology

Twenty-five tinytag transit data loggers (Gemini, TG-0050) were installed at different locations across the field to capture topographic effects on the daily course of temperature. The data loggers were protected by PVC pipe of 10 cm diameter, 30 cm in length, open from both the sides with a longitudinal slit of about 3 cm over the length of pipe to facilitate air movement. The complete setups were erected at the chosen locations over the entire field at a height of 0.8 m to represent crop head height.

Daily temperatures were recorded every 15 minutes across the field. The exact position and elevation of data loggers were obtained with a Global Positioning System. The digital elevation model was derived and aspect and slope were calculated using ArcView 3.2™. A total of 40 days of data was collected between mid September and early November. Twenty days of data were used for model development and twenty independent records were left and later used during model validation.

Results and Discussion

Results from the correlation and multiple linear regression analysis are given in Tables 1, 2 and 3.

Table 1. Correlation matrix

Tmax	1.000		
AvgTmax	0.968*	1.000	
Tmin	0.196*	0.198*	1.000

AvgTmin	0.197*	0.203*	0.974*	1.000			
Alt	-0.007	0.000	-0.014	0.000	1.000		
Aspect	0.018	0.000	-0.010	0.000	0.144*	1.000	
Slope	-0.018	0.000	0.069	0.000	0.125*	-0.032	1.000
	Tmax	AvgTmax	Tmin	AvgTmin	Alt	Aspect	Slope

Tmax, AvgTmax, Tmin, AvgTmin and Alt are: daily maximum temperature at a location, average daily maximum temperature of the paddock, daily minimum temperature at a location, average daily minimum temperature of the paddock, and elevation, respectively. Correlations marked with an asterisk are significant at $p < 0.05$.

Table 2. Estimates of parameters of the regression model describing maximum temperature (R^2 = 0.94, n = 377, F probability <0.001)

Parameter	Estimate	SE	t (df = 372)	t probability
Constant	0.83	1.62	0.51	0.609
Elevation	-0.0103	0.0185	-0.56	0.579
Aspect	0.000657	0.000465	1.41	0.158
Slope	-2.15	1.66	-1.29	0.197
Avg. max. padd. temp	1.0001	0.0134	74.40	<0.001

Table 3. Estimates of parameters of the regression model describing minimum temperature (R^2 = 0.95, n = 377, F probability <0.001)

Parameter	Estimate	SE	t (372)	t probability
Constant	1.728	0.972	1.78	0.076
Elevation	-0.217	0.0113	-1.93	0.055
Aspect	-0.000107	0.000284	-0.38	0.705
Slope	6.42	1.01	6.33	<0.001

Avg. min. padd. temp.	1.0002	0.0114	87.51	<0.001

Elevation was negatively correlated with both observed maximum temperatures and minimum temperatures. Aspect was positively correlated with maximum temperatures and negatively correlated with minimum temperatures, whereas slope was negatively correlated with maximum temperatures and positively correlated with minimum temperatures.

During calibration, the models for maximum and minimum temperatures explained 94% and 95% of the observed variability, respectively (n = 377, P <0.001 in both the cases).

Results from regression analysis show that a steep slope led to lower maximum temperatures and high minimum temperatures probably by rapidly draining cool air downwards. The lower values of aspect (0-45?, north-eastern exposures) led to high minimum temperatures during night as they received more heat during the day. Results show that high elevation resulted in low temperature, probably as a result of the combination of all three landscape properties i.e. elevation, aspect and slope. Points of higher elevation, flatter slope and facing south-west (higher value of aspect, 180-225?) led to lower minimum temperatures, whereas points at higher elevation on steeper slopes and facing north-east (lower aspect value) led to higher minimum temperatures.

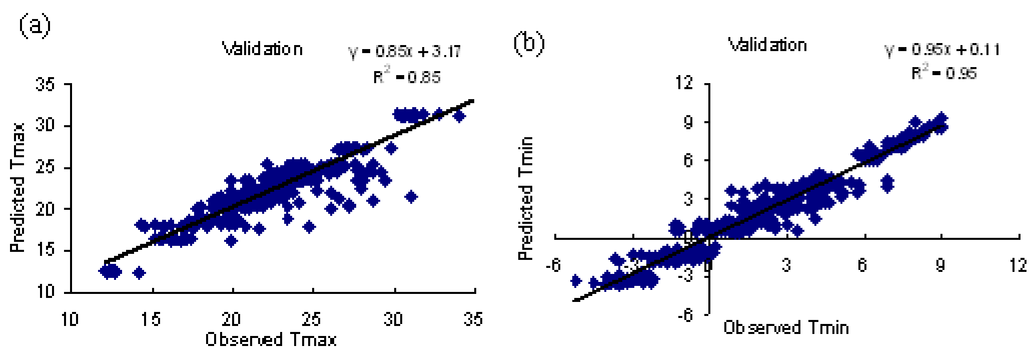

Fig. 1. Observed and predicted maximum (a) and minimum (b) temperatures during validation.

Figures 1(a) and 1(b) show the relationship between observed and predicted (from the regression models) maximum and minimum temperatures obtained during validation. It is evident from the above Figures that minimum temperature was far better predicted by the model (R^2 = 0.95) than was the maximum temperature (R^2 = 0.85). This could be attributed to passing clouds that might affect maximum temperature during the daytime, or to wind speed.

Figure 2 shows that the elevation varied by almost 10 metres across the paddock.

Figures 3(a) and 3(b) show the residuals (observed minus predicted) for maximum and minimum temperatures on 1st October 2003. For this particular day the residuals ranged from –1.3 to +1?C in the case of maximum temperature and from 0.1 to 1.1?C for minimum temperature. This indicated no large residuals in both the cases. Residuals changed from day to day, however no particular bias was observed when all the data were pooled together (not shown).

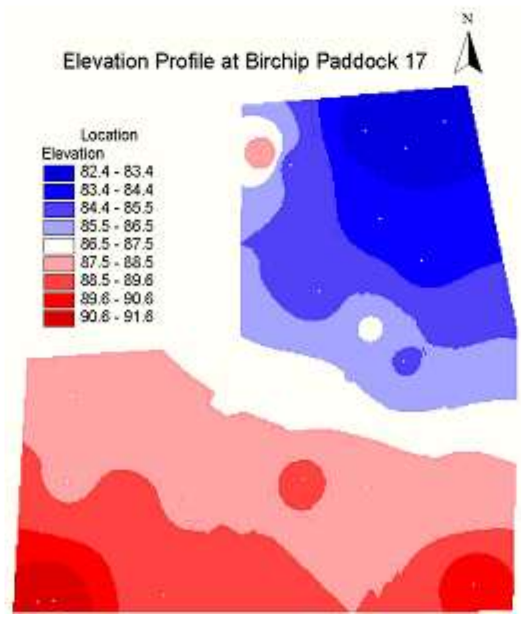

Fig. 2. Variations in elevation across the paddock.

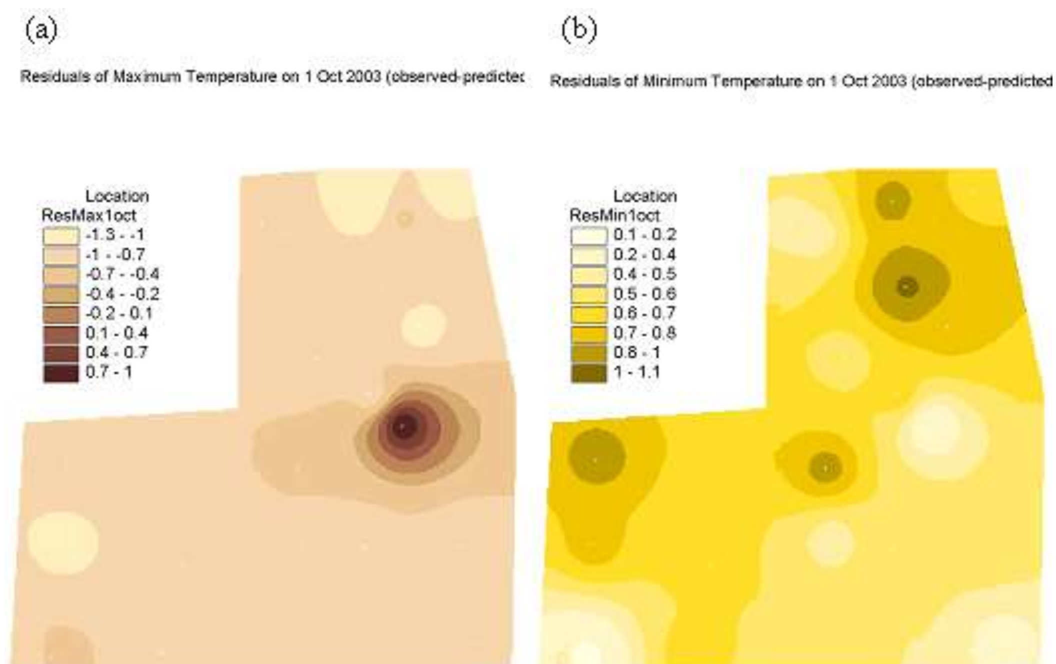

Fig. 3. Difference between observed and predicted maximum (a) and minimum (b) temperatures during validation (Oct 1, 2003).

Conclusion

The spatial temperature variations in the paddock were related to topographical parameters of the landscape. Zones where extreme temperatures are likely to occur can be identified. It is evident from the results that the points of high elevation are more likely have low temperature but the combination of elevation, aspect and slope eventually determines where extreme temperatures occur. Steep slope resulted in low daily maximum temperatures and high minimum temperatures. Spatial variability in minimum temperatures was better explained by topography than was variability in maximum temperatures, which might have been affected by cloud or spatial variability in soil albedo, surface soil moisture and soil cover.

References

Cawood R (1996). Climate, Temperature and Crop Production in South-eastern Australia. Agriculture Victoria. Victorian Institute for Dryland Agriculture, Horsham, VIC 3400. 312 pp.

Lookingbill TR and Urban DL (2003). Spatial estimation of air temperature differences for landscape-scale studies in montane environments. Agricultural and Forest Meteorology 114, 141–151.

Russell G and Wilson GW (1994). An agri-pedo-climatological knowledge base of wheat in Europe. Joint Research Centre, EU, Luxembourg, 158 pp.

Slafer GA and Slavin R (1991). Developmental base temperature in different phenological phases of wheat (*Triticum aestivum*). J. Exp. Bot., 42 (241), 1077-1082.

Wheeler TR, Batts GR, Ellis RH, Hadley P and Morison JIL (1996). Growth and yield of winter wheat (*Triticum aestivum* L.) crops in response to CO_2 and temperature. J. Agric. Sci., Camb., 127, 37-48.