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Welcome from Editor

It is my pleasure to bring to you the compiled papers from the Science Day of the AFAC and Bushfire CRC Annual Conference, held in the Sydney Convention Centre on the 1st of September 2011.

These papers were anonymously referred. I would like to express my gratitude to all the referees who agreed to take on this task diligently. I would also like to extend my gratitude to all those involved in the organising, and conducting of the Science Day.

The range of papers spans many different disciplines, and really reflects the breadth of the work being undertaken, The Science Day ran four steams covering Fire behaviour and weather; Operations; Land Management and Social Science. Not all papers presented are included in these proceedings as some authors opted to not supply full papers.

The full presentations from the Science Day and the posters from the Bushfire CRC are available on the Bushfire CRC website www.bushfirecrc.com.

Richard Thornton

November 2011.

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Assessing Potential House Losses Using PHOENIX RapidFire

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Abstract

There has been a considerable body of work identifying the characteristics of houses and their surroundings that contribute to house loss in bushfires (Wilson & Ferguson 1986, Ramsey et al. 1987, Cohen 1995, Blanchi et al. 2006, Blanchi et al. 2010, Mell et al. 2010) . However, the characteristics of a bushfire, such as flame length, intensity, size, and spotting characteristics are also important. PHOENIX RapidFire characterizes fire in a spatially and temporally explicit way. One logical use of a simulation model such as PHOENIX RapidFire is to estimate the number of houses that might be lost when they are impacted by a bushfire. The recent Black Saturday fires in Victoria, have provided an opportunity to evaluate the utility of PHOENIX RapidFire to assess potential for house losses under Black Saturday conditions) nt conditions associated with about 2000 house losses. This dataset has provided an opportunity to develop a potentially better predictive model of house loss for use by emergency response agencies during a bushfire event as well as provide criteria to evaluate the potential benefits of a range of planning and land management activities on reducing the impact of bushfires on houses.

This paper presents the results from this analysis and the algorithms developed for predicting house loss based on modelled fire behaviour characteristics from PHOENIX RapidFire.

Introduction

Barrow (1945) was the first person in Australia to record the fact that house loss in bushfires is not a random event. He identified that embers were a major house ignition source, and that building details rather than building materials were important to house survival, in the 1944 fire in Beaumaris, then on the outskirts of Melbourne. Since then, research by Wilson and Ferguson (1985), Ramsey *et al.* (1987), Leonard and Blanchi (2005), Blanchi *et al.* (2006) and others have increased our understanding of the mechanisms by which houses are ignited in bushfires and other factors leading to their destruction. These studies have identified that factors related to fire characteristics such as fireline intensity, flame height, and ember production are important to the probability of house loss. They have also shown the importance of building design, construction materials, degree of maintenance and siting were also important. And an additional factor of high importance is whether or not someone was actively defending the home by extinguishing ignitions while they were in their early stages of development.

This study investigates the feasibility of using PHOENIX RapidFire (Tolhurst *et al.* 2008), a fire characterization simulator, to adequately spatially and temporally describe some key fire characteristics, to find a statistically significant connection between these modelled fire characteristics and the known pattern of house loss from the 2009 Black Saturday bushfires in Victoria.

Methods

An extensive survey of houses, both damaged and undamaged, in the areas affected by the Black Saturday fires in Victoria was coordinated by the Bushfire CRC. This provided an unusually large dataset for model evaluation. Records from 5024 houses surveyed were used in this analysis. The dataset used was supplied by Geoscience Australia. The dataset comprised houses that were affected by the Churchill, Murrindindi and Kilmore East Fires. Of the sample 2640 houses were either damaged or destroyed by the fires and 2381 survived. The Black Saturday fires were large (about 300,000 ha burnt in the first day) and intense and occurred in largely dissected mountainous terrain with pronounced spotting being a major feature of the fire behaviour. A further 58 houses were included in the sample from the Deep Lead fire, near Stawell, from 2005, 13 of which were destroyed. The Deep Lead fire burnt in mixed agricultural and remnant bushland in gently undulating terrain and was primarily a wind-driven grass fire with minimal spotting contributing to the overall fire behaviour, providing a contrasting set of conditions to the Black Saturday fires. All houses surveyed that had been damaged or destroyed were classified as "Lost" in this analysis and all others were classified as "Survived".

PHOENIX RapidFire is a spatio-temporal fire characterization model (Tolhurst *et al.* 2008) that estimates fire behaviour characteristics as it burns through a landscape. Fire spread is calculated as a series of continuous variables across the landscape, but the fire characteristics are only recorded within a fixed square grid, the cell-size of which can be selected by the user, but in this analysis, a 180 x 180 m cell size was used. This grid size

(3.24 ha) provided sufficient detail to see the fire pattern across the landscape without unnecessarily consuming computer time on details that make little difference to the fire pattern. In each cell, 10 input variables related to fuel, terrain, and access are recorded and 14 output variables related to fire characteristics and modified winds are recorded. The fire characteristics are: the time a cell is burnt since ignition, its average rate of spread and associated fireline intensity (Byram 1959), the time when the first embers arrived since ignition, the maximum distance embers have travelled to reach this cell, cumulative ember density landing in a cell until it ignited, the time from ignition when fire was suppressed, the time from ignition when fire self-extinguished, the average flame height when fire first entered cell, the flame depth when fire first entered cell (assuming a 10 second residence time in grassland and 80 seconds in shrubland and forests), maximum relative convective updraught strength[4] in cell, fine fuel moisture content, local wind speed as affected by terrain, and local wind direction as affected by terrain. In the analysis here, two additional fire variables were derived from the basic 14, these being flame cross-sectional area (FlameXS) which assumed the flame was a triangle with a base length (L) equal to the flame depth and the triangle height (H) being equal to the flame height (Fig. 1). The second derived variable was "convection density" where the local convective strength was averaged across an area with a 2000 m radius and recorded with 100 m resolution using a kernel density routine in ESRI ArcGIS. The house locations were intersected with the fire characteristics in ArcGIS to produce a dataset that connected the house location with the simulated fire characteristics. It was this dataset that was used in the analysis report here.

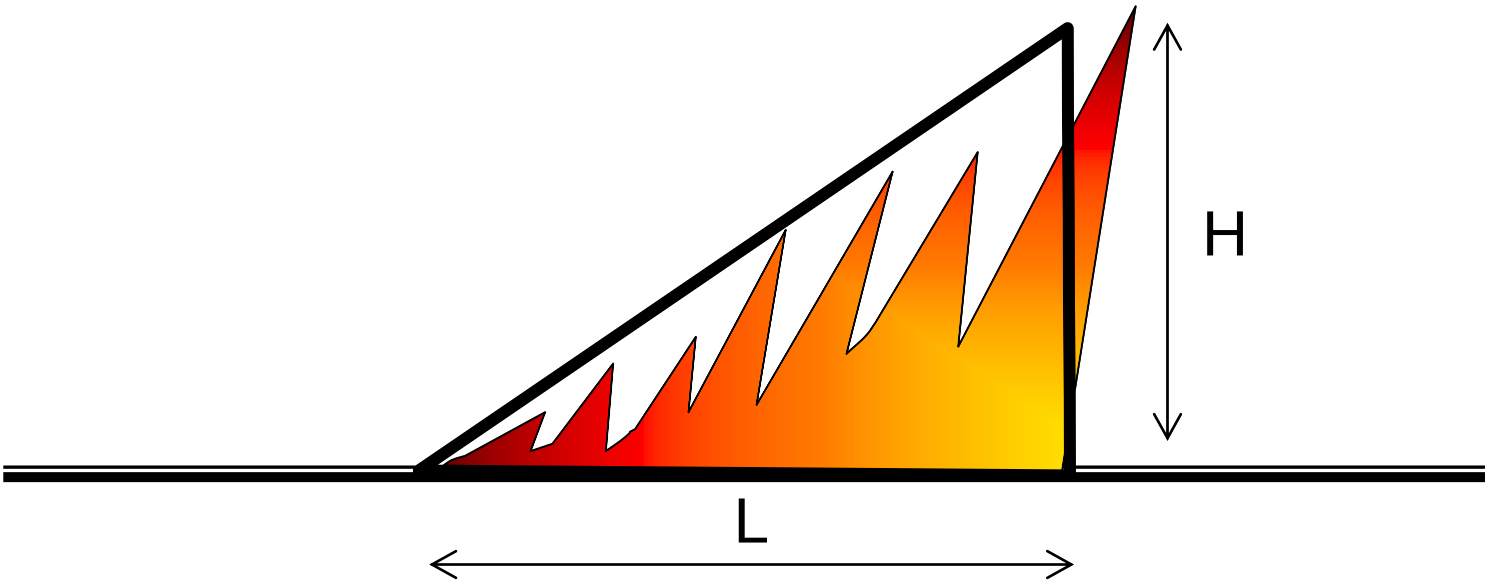

Figure 1. Diagramatic representation of how the flame cross-sectional area is calculated. H is the flame height and L is the flame base length.

Both univariate and multivariate statistical analyses were used. Univariate analyses were primarily non-linear regression analyses. Before the regression analysis, output variables were grouped into classes and the probability of loss for each class was based on the

[4] Relative Convective Strength was calculated as the total energy output (MW) of a segment of the fire perimeter which was assessed to be drawn into a common convection centre, at each timestep of the modelling process.

number of houses "Lost" as a proportion of the total number of houses in each class. These data were graphed for each of variables and regression analysis was made to find the best regression model to describe the relationship between the probability of house loss and the variable of interest. Multivariate analysis consisted of a Principal Component Analysis and Logistic regression using Minitab version 16 (Minitab Inc., 2010).

Results

The multivariate analysis (Principle Component Analysis) showed that there was a strong correlation between the local convection strength ("Convect") and the generalized convection density ("ConvectDens") (Fig. 2). Similarly, there was a strong correlation between flame height ("FlameHt"), flame depth ("FlameDpth") and fireline intensity ("Intensity"). Flame cross-sectional area was correlated to the other flame dimensions, but showed some independence. Modelled ember density ("Embers") was independent of all other fire variables, but explained a smaller proportion of the variation in the data than the other variables. This analysis shows that there are three relatively independent factors describing the simulated fire characteristics associated with house loss on Black Saturday - "Ember Density", Flame Height/Flame Depth/Flame Cross-sectional area/Fireline Intensity, and Convective Strength/Convective Strength Density.

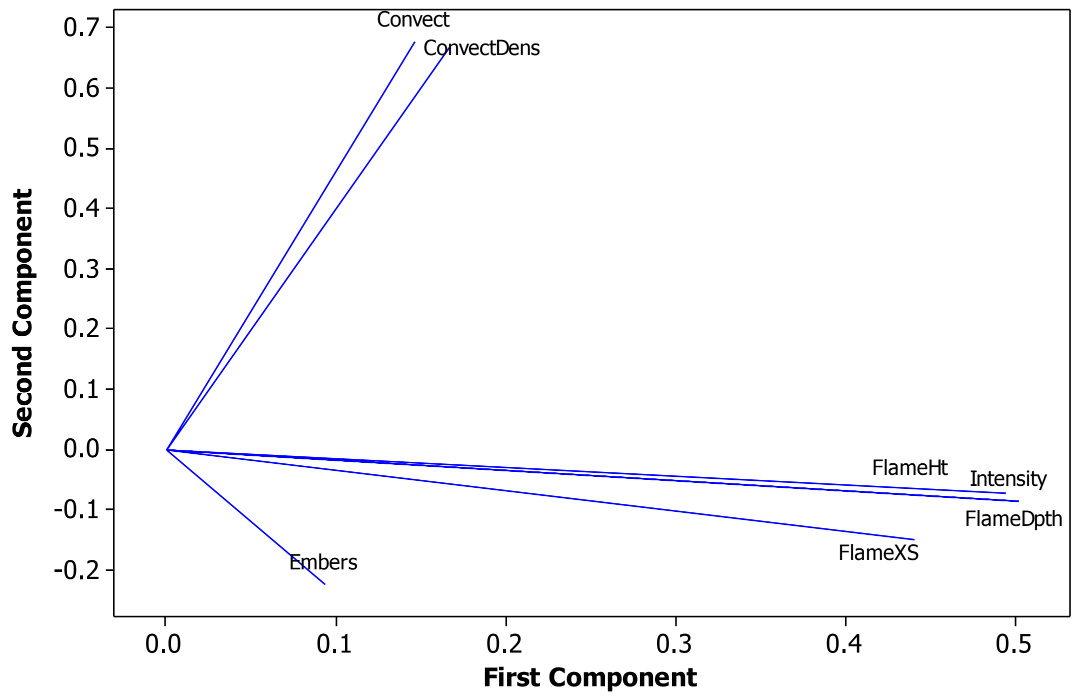

Figure 2. Principle Component Analysis of predicted fire variables for houses destroyed in the Kilmore East, Murrindindi and Churchill fires on Black Saturday 2009.

Analysis of individual fire characteristics showed significant trends between the magnitude of each factor and the probability of house loss (Figures 3 to 8). The line of best fit for each factor is given in Table 1.

Table 1. Line of best fit regressions for a number of modelled fire parameters and the probability of house loss.

Fire Parameter	**Model**	**R value**
Flame height (m)	Pr(Loss) = 0.8348/(1+1.10667*EXP(-0.05726*FlameHt))	0.896
Flame cross-sectional area (m^2)	Pr(Loss) = 0.40935*FlameXS^0.0793	0.935
Ember density (No./m^2)	Pr(Loss) = 0.5715*(1.1747-EXP(-0.9513*Ember))	0.907
Fireline Intensity (kW/m)	Pr(Loss) = 1/(4.5278-1.7366*Intensity^0.05456)	0.952
Convection	Pr(Loss) = 0.2543*(Convect+5.6966)^0.104	0.981
Convection Density	Pr(Loss) = 0.9303-0.7554*EXP(-0.0000926*ConvectDens^0.7085)	0.989

If instead of predicting a probability of house loss, each house was assessed on the basis of a binary classification of "Lost" or "Survived", then the threshold values of each fire parameter that would be define the 50/50 chance of loss or survival are listed in Table 2. This analysis does not consider the interaction of variables, e.g. the enhancing of house ignition by embers when there is also a significant radiation heat load, which would be confounded in these thresholds. For example, it is likely that a house might be subjected to both radiation and ember attack, but these factors cannot be separated in this analysis.

Table 2. 50% survival/loss threshold value for each fire parameter based on the line-of-best-fit regression lines in Table 1.

Fire Parameter	**50/50 Survival Threshold Value**
Flame height (m)	9 m
Flame cross-sectional area (m^2)	13 m^2
Ember density (#/m^2)	1.3 embers/m^2
Fireline Intensity (kW/m)	1,000 kW/m
Convection	700

Convection Density	220,000

Two binary logistic regressions were fitted to the house survival/loss data using Logit. A range of factor combinations were explored, but only two combinations were considered to be generally applicable. Three factors were used in each of the two models. Both included Flame Cross-sectional Area and Ember Density. The difference between the two regressions was the use of either Convective Strength or Convective Density. Both these regressions are statistically significant at the p=0.001 level and the ranked-based non-parametric statistic, Somers' D (Newson 2002), indicates that 51% of the variation in the probability of house loss is explained by equation 1 and 42% of the variation is explained by equation 2.

Logistic equation 1.

Pr(Loss)=1-EXP(0.63076-0.0000021*ConvectDens-0.0002662*FlameXS-0.01832*Embers)/(1+EXP(0.63076-0.0000021*ConvectDens-0.0002662*FlameXS-0.01832*Embers))

Somers' D = 0.51

Logistic equation 2.

Pr(Loss) =1-EXP(0.2894-0.000487*FlameXS-0.02003*Embers-0.0000157*Convect)/(1+EXP(0.2894-0.000487*FlameXS-0.02003*Embers-0.0000157*Convect))

Somers' D = 0.42

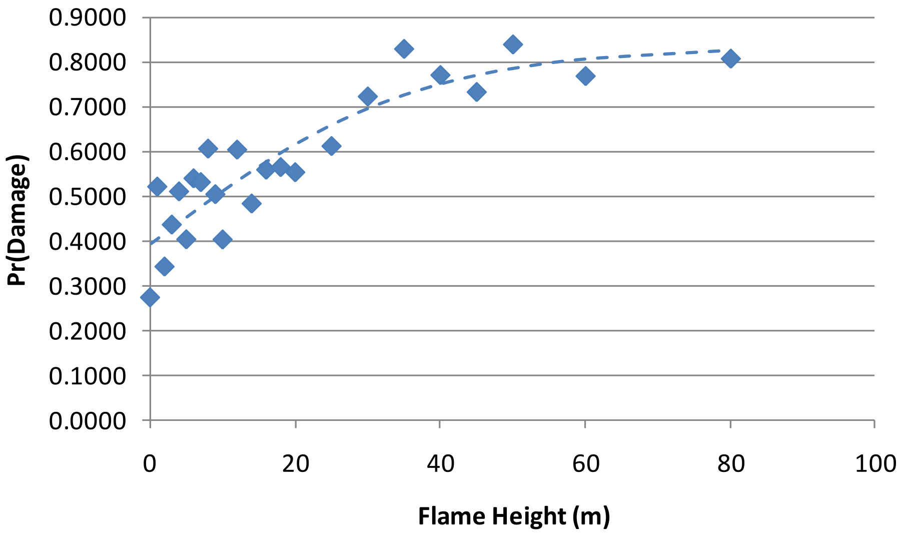

Figure 3. Probability of house loss when associated with predicted flame height.

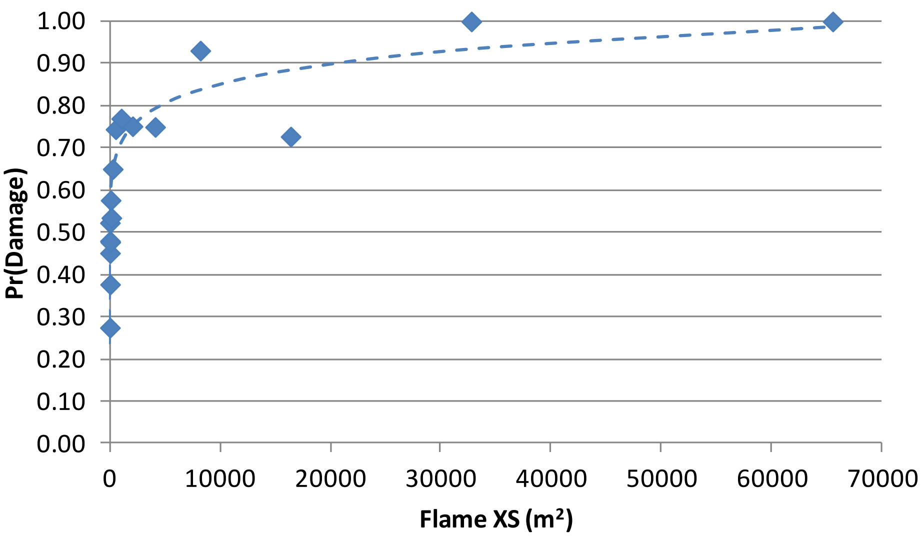

Figure 4. Probability of house loss associated with predicted flame cross-sectional area.

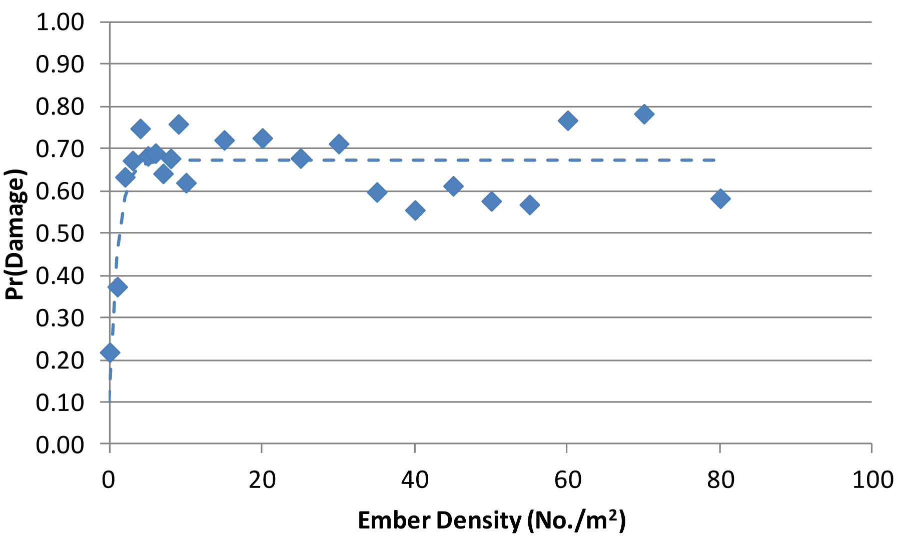

Figure 5. Probability of house loss associated with predicted ember density.

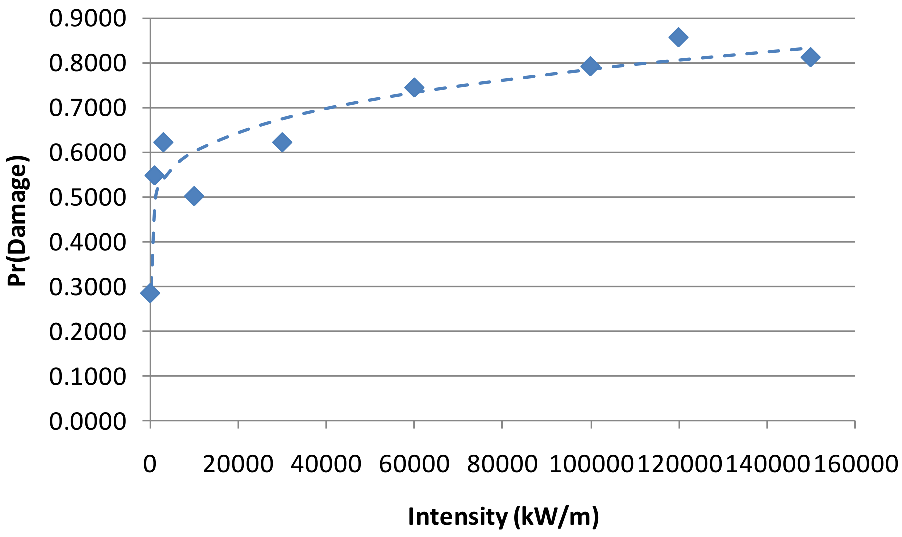

Figure 6. Probability of house loss associated with predicted fireline intensity.

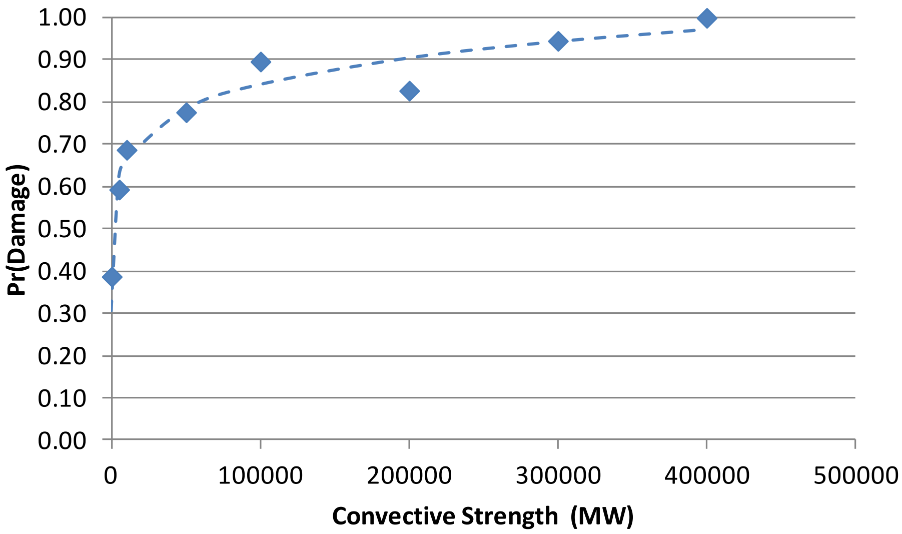

Figure 7. Probability of house loss associated with predicted convective strength.

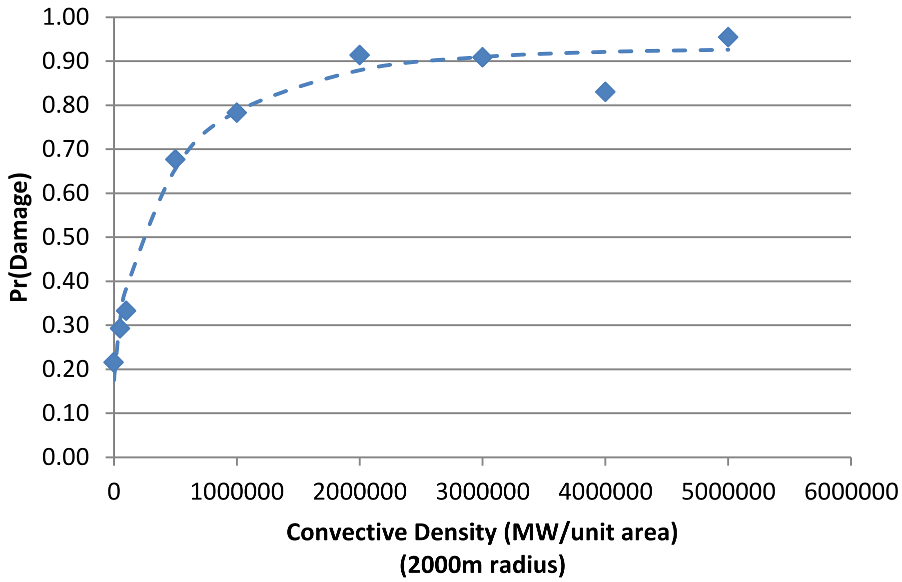

Figure 8. Probability of house loss associated with predicted convective strength smoothed over a 2000 m radius.

Table 2. Average probability of house loss predicted by each of the proposed models (Table 1 and Logistic equations) compared with the actual house status "Lost"/"Surv", subdivided by fire event. (Flame XS = flame cross-sectional area, EmberDens = ember density, Intensity = fireline intensity, Convection = convective strength, ConvectDens = convective strength density.)

	Logit1		Logit2		FlameXS		FlameHt		EmberDens		Intensity		Convection		ConvectDens	
FIRE	Lost	Surv	Lost	Surv	Lost	Surv	Lost	Surv	Lost	Surv	Lost	Surv	Lost	Surv	Lost	Surv
Churchill	0.59	0.46	0.58	0.50	0.52	0.35	0.53	0.48	0.61	0.34	0.58	0.47	0.50	0.39	0.52	0.35
Kilmore	0.61	0.45	0.58	0.49	0.53	0.41	0.58	0.49	0.53	0.37	0.57	0.48	0.49	0.38	0.52	0.35
Murrindindi	0.54	0.41	0.50	0.45	0.48	0.33	0.50	0.46	0.52	0.24	0.54	0.43	0.40	0.34	0.52	0.33
Stawell	0.36	0.37	0.43	0.44	0.51	0.47	0.44	0.44	0.13	0.15	0.60	0.57	0.33	0.38	0.25	0.27
Total	**0.59**	**0.44**	**0.56**	**0.48**	**0.52**	**0.40**	**0.55**	**0.48**	**0.53**	**0.34**	**0.56**	**0.47**	**0.47**	**0.38**	**0.52**	**0.34**

The average probabilities of house loss predicted by various models compared to the actual status of each house on an individual basis is not strongly differentiated, certainly not as strongly differentiated as might be expected from the consistency of the relationships shown in Figures 2 to 7. This is interpreted to suggest that the relationships between the fire characteristics predicted by PHOENIX RapidFire and the probability of house loss are not a very good basis for predicting the probability of loss of individual houses even though the predictions about the general house loss for groups of houses is quite strong. In all cases in Table 2, the averaged predicted probability of house loss is higher for the damaged and destroyed houses ("Lost") than for the houses that survived ("Surv"), so each of the models work on average

Table 2 shows an interesting distinction between the three fires analyzed from Black Saturday and the Stawell fire. With most of the models, the predicted probability of loss is less than 0.5 and distinctly less than the probabilities for the Black Saturday fires. The Stawell fire was a fast moving, wind-driven grassfire largely in grassland with only scattered areas of forest and woodland, quite different to the situation in the Kilmore East, Murrindindi and Churchill fires which were largely in mountainous forested country and developed very large convective plumes. Even though the "EmberDens", "ConvectDens" and "Logit1" models gave the best overall prediction of house loss, it was the model based on the Flame Cross-sectional Area ("FlameXS") which gave the most consistent prediction regardless of whether the fire was in grassland or forest.

In all cases, except one, the average probability of house loss predicted for surviving houses was less than 0.5. The sole exception was for the houses surviving the Stawell fire when using the predictive model based on Fireline Intensity. The intensity of the Stawell fire was dominated by the rapid rate of spread rather than the effect of fuels and topography, as would be expected in a grassland-dominated fire.

Discussion

House loss in bushfires results from the combination of many interacting factors including characteristics of the house construction, the presence or not of fire suppression efforts during the fire event, the level of garden (fuel) and house maintenance, the proximity of flammable objects to the house, the nature of the bushfire itself, the position of the house in the terrain and an element of chance (Wilson & Ferguson 1986, Blanchi *et al.* 2006). Previous attempts to predict bushfire threat in terms of potential house loss using a static view of geospatial data such as vegetation, slope, aspect and potential fire intensity, had limited success in identifying houses most at risk (Lowell *et al.* 2009). It is not surprising that it is difficult to accurately predict which specific houses will survive and which will be lost when it is not possible to accurately quantify all the interacting factors during a fire event. However, there are some factors which can be adequately quantified and have a significant bearing on the probability of a house surviving or being destroyed during a bushfire. These probability ratings can give a reasonable prediction of the likely number of houses that will be lost in a neighborhood, without being certain about specific houses and this has been demonstrated in this study. A dynamic view of fire behaviour as provided by a simulator such as PHOENIX RapidFire is likely to result in better predictive ability than a bushfire threat model based on a static view of fire.

Detailed analysis of the circumstances associated with house loss in bushfires has identified the critical factors. Some of these factors are related to the nature of fire and it is these that have been used here. Flame characteristics such as flame height and flame cross-sectional area affect the radiative heat load on a house and the likelihood of flame contact, so it was not surprising to find a strong association between the flame characteristics predicted by PHOENIX RapidFire and the known level of house loss. Fireline intensity was also identified by Wilson and Ferguson (1986) as being strongly associated with house loss and again, there was a strong relationship between the modelled fire intensity and the probability of house loss. Embers have been associated with about 90% of all house losses as either the primary ignition source or an ignition source in combination with other factors (Leonard and Blanchi 2005). In the analysis here, the probability of house loss increases rapidly with ember density and then seems to "saturate" at relatively low levels. The addition of further embers does not change the probability of house loss, and the probability of house loss with embers alone does not exceed about 70%. A unique aspect of using PHOENIX RapidFire to assess the nature of the fire is the ability to calculate the local convective strength. Strong convective influences only occur in large intense fires where the weather, fuel and topography combine to create suitable convective development. Convective strength has not been a factor specifically included in house loss studies because of the difficulty in determining it. Computer modelling makes this possible, even if the method used to calculate convection in PHOENIX RapidFire is not a 3-dimensional fluid-dynamic model it provide sufficient convective characteristics to correlate local fire behaviour with potential house loss. In this study, the convective strength (and convective density) was strongly correlated with the house loss in the fires of Black Saturday in Victoria, but was not as important in the Stawell fire in 2005 where grass fuels dominated and the topography was flat to undulating.

The most robust model for predicting the probability of house loss is the logistical model that combines the effects of flame cross-sectional area, ember density and convective strength density. These three variables represent the three main components of the data shown in Fig.1. This model incorporates the main factors, related to the fire itself, that are known to be associated with house loss. However, the model using just flame cross-sectional area would give a more consistent prediction of house loss across contrasting fire types - flat grassland fires compared with fires in forested hills and mountains. Flame characteristics explain the greatest amount of variation in the house loss data (Fig.1). Given the history of greater house loss in forested hills and mountains, it would seem prudent to use the logistical model as the first choice in complex landscapes.

Conclusions

PHOENIX RapidFire provides an adequate spatial and temporal characterization of bushfires to be able to estimate the probability of house loss at a neighborhood scale. Although the fire characterization by PHOENIX RapidFire has not been, nor is ever likely to be validated at a scale similar to that used here (3.24 ha) it does provide a realistic range of fire behaviour characteristics and spread that can be used for analyses such as this. A logistic model incorporating flame cross-sectional area, ember density, and convective strength density produced the most robust model overall. A non-linear regression model using just flame cross-sectional area gave more reliable results in grassland dominated landscapes.

House design and level of preparation and maintenance were not considered in this modelling process, nor was the level of active defense during the passage of the fire. These are known to also be important contributing factors to the probability of house survival, but could not be included in this analysis due to lack of adequate data.

The predicted level of house loss using simulated fire characteristics, provides a useful basis for assessing the relative threat of fire in a range of circumstances. It is therefore expected that this modelling approach could be used to evaluate the relative benefits of different fire mitigation options such as broadscale planned burning and fuel modification in and around townships and small communities.

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