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A UNIFIED APPROACH TO FIRE SPREAD MODELLING

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EXTENDED ABSTRACT

A UNIFIED APPROACH TO FIRE SPREAD MODELLING

One of the main goals of bushfire research is to provide a relatively simple and timely answer to the question "What is the fires' forward rate of spread?" Indeed, pursuit of such an answer has engaged some of the brightest minds in wildland fire science, and has produced a variety of fire spread models that apply across a number of common vegetation or fuel types. In Australia, these models date back to the 1950s-60s, with the work of Alan McArthur, and extend through to the current day with the most recent developments in shrubland fire spread models and refinements to the curing function in the CSIRO grassland fire spread model. In the present work we consider the way that meteorological factors are incorporated into the suite of existing fire spread models, which encompass a variety of different fuel types, and discuss an approach that unifies their inclusion. The utility of this unified modelling approach is demonstrated via model comparison using real meteorological data over a range of vegetation types. In particular, we demonstrate that the meteorological (i.e. non-fuel) sub-models of the current suite of operational models, which are of many and varied functional form, can be replaced by a single, unified, two-parameter model, with no appreciable loss in model performance. The unified model has the distinct advantage of being conceptually straightforward and extremely parsimonious compared to current operational approaches. The existence of a simple, yet effective, unified approach to fire spread modelling has implications for initiatives such as the National Fire Danger Rating project, as it establishes a common modelling basis that can be applied to the many different fuel types that are encountered across the nation.

FIRE SPREAD MODELS

We consider current operational models for the following fuel types: grasslands; buttongrass moorland; temperate shrubland; South Australian mallee-heath; and dry eucalypt forest. The rate of spread models for each of these fuel types are described in detail by Cruz et al. (2015).

In this study we specifically focus on how the rates of spread derived from the models mentioned above depend on the fire weather variables: temperature, relative humidity and wind speed. Fuel-related factors such as availability and structural descriptors (e.g. fuel height) are assumed constant for each fuel type.

It is of interest to note the number of model parameters that are associated with each of the rate of spread models for the different fuel types considered. These parameters represent degrees of freedom in the model, and have to be determined through regression-type analyses of empirical data relating to the rate of spread and environmental predictor variables. Ignoring their fuel dependent components, the grassland model has 10 parameters (Cheney et al., 1998), the buttongrass moorland model has 6 parameters (Marsden-Smedley and Catchpole, 1995), the temperate shrubland model has 9 parameters (Anderson et al., 2015), the S.A. mallee-heath model has 7 parameters (Cruz et al., 2010), and the dry eucalypt forest model has 13 parameters (Cheney et al., 2012).

A UNIVERSAL FIRE SPREAD INDEX

Previous work (Sharples et al., 2009a; Sharples and Matthews, 2011; Sharples and McRae, 2012) has considered the utility of the following simple dimensionless index in describing fuel moisture content. The *fuel moisture index* is defined as:

$$FMI = 10 - 0.25(T - RH),$$

where T is air temperature (°C) and RH is relative humidity (%).

The FMI has been combined with wind speed in simple functional forms, which have been shown to provide estimates of fire danger and rates of spread that are comparable to those derived from accepted models (Sharples et al., 2009b; Sharples and McRae, 2013). In this work, we extend this idea, and examine how predictions from a simple, two-parameter model for fire spread, based on wind speed U and FMI, compares to those from the various models for different fuel types. The particular model, which we refer to as the *spread index*, is:

$$S(\mu, p) = \left(\frac{\max(1, U)}{FMI + \mu}\right)^p,$$

where μ and p are the two parameters defining the model.

To facilitate the comparison between the current operational models and the spread index, we use half-hourly fire weather data recorded at Canberra Airport between November 2006 – March 2007; that is, approximately a fire season's worth of numbers.

RESULTS

In this preliminary work the spread index parameters μ and p were varied by hand until a good fit was obtained between predictions of the spread index and those arising from each of the rate of spread models for grassland, buttongrass, temperate shrubland, S.A. mallee-heath and dry eucalypt forest. An example of a comparison of the predictions of the spread index compared to the predictions of the temperate shrubland model (Anderson et al., 2015) and the dry eucalypt model (Cheney et al., 2012) can be seen in Figure 1. The parameter values used to calculate the spread index in each case are listed in Table 1. Note that in each case the spread index values have been scaled so that their mean equals the mean of the predictions from the fuel-specific model.

Table 1 summarizes the results across all the different rate of spread models. In the worst case the spread index accounts for around 94% of the variability in the dry eucalypt forest rate of spread model, while in the best case it accounts for over 99% of the variability in buttongrass moorland model. The table also indicates root mean square differences between the fuel-specific models and the spread index of 5-15%, with the exception of the dry eucalypt forest model, which has a root mean square difference of 33%. Root mean square differences have been expressed as a percentage of the mean value of the fuel-specific model predictions in this comparison.

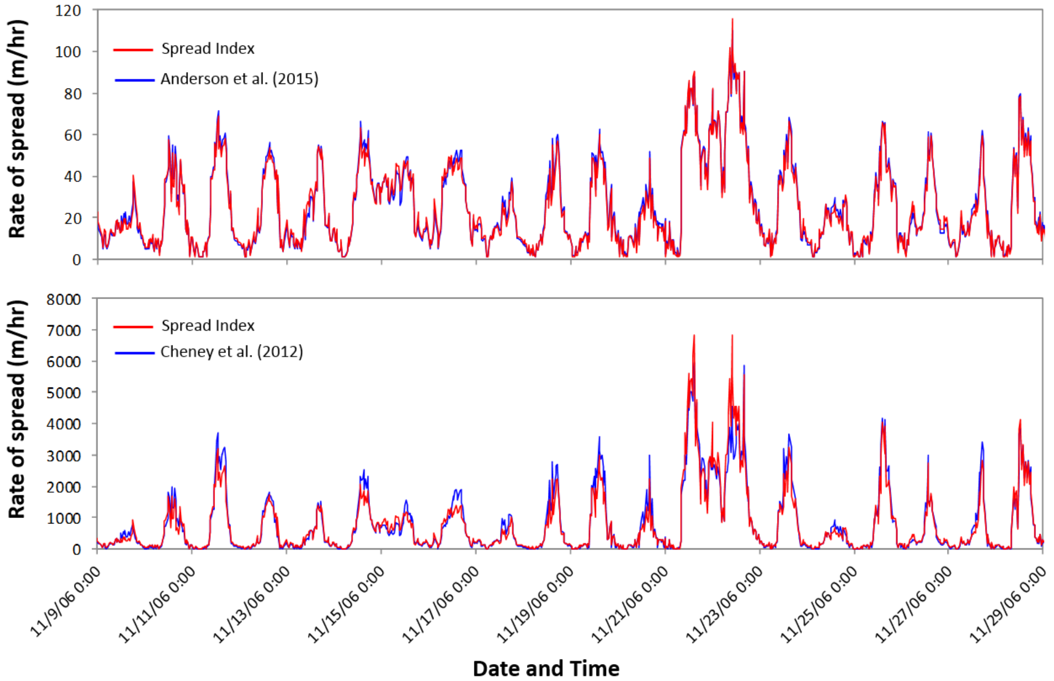

Figure 1. Rate of spread predictions from the temperate shrubland model of anderson et al. (2015) and the dry eucalypt forest model of Cheney et al. (2012) compared to those from the spread index. The spread index values have been scaled in each case so that their mean value matches the mean value of the fuel-specific model predictions.

Fuel type	No. model parameters	μ	p	Correlation with spread index (R^2)	Root mean square difference
Grassland	10	5	1.00	0.9880	15%
Buttongrass moorland	6	80	1.34	0.9968	5%
Temperate shrubland	9	10	1.00	0.9893	8%
S.A. mallee-heath	7	9	1.28	0.9896	13%
Dry eucalypt forest	13	3	1.40	0.9412	33%

Table 1. Results of comparison of the spread index with the various rate of spread models. The optimal spread index parameters are listed along with the inter-model correlations and root mean square errors.

CONCLUSIONS

Predictions from the meteorological sub-models of five state-of-the-art fire spread models were compared with predictions derived from a single two-parameter fire spread index. The results indicated that the simple spread index was able to reproduce the predictions of the more complicated models to a remarkable degree of accuracy (R^2 = 0.94-0.99). The results further suggest that the state-of-the-art models are considerably over-complicated: the predictions from models with 6-13 parameters can all be accurately emulated by a model with only two parameters (or three parameters, if a scaling/calibration factor is included). This indicates that the current suite of operational models have about 2-6 times more degrees of freedom than necessary. Indeed, the spread index offers a far more parsimonious approach to modelling rate of spread, is far more conceptually simple, and provides a unified way of assessing rate of spread across a variety of fuel types.

REFERENCES

1 Anderson WR, Cruz MG, Fernandes PM, McCaw L, Vega JA, Bradstock RA, Fogarty L, Gould J, McCarthy G, Marsden-Smedley JB, Matthews S. *A generic, empirical-based model for predicting rate of fire spread in shrublands*. International Journal of Wildland Fire 2015; 24: 443-460.

2 Cheney NP, Gould JS, Catchpole WR. *Prediction of fire spread in grasslands*. International Journal of Wildland Fire 1998; 8: 1-3.

3 Cheney NP, Gould JS, McCaw WL, Anderson WR. *Predicting fire behaviour in dry eucalypt forest in southern Australia*. Forest Ecology and Management 2012; 280: 120-131.

4 Cruz MG, Matthews S, Gould J, Ellis P, Henderson M, Knight I, Watters J. *Fire dynamics in mallee-heath: fuel, weather and fire behaviour prediction in south Australian semi-arid shrublands*. Bushfire Cooperative Research Centre, Report A; 2010.

5 Cruz MG, Gould JS, Alexander ME, Sullivan AL, McCaw WL, Matthews S. *A Guide to Rate of Fire Spread Models for Australian Vegetation*. CSIRO Land and Water Flagship and AFAC: Canberra, ACT and Melbourne, VIC; 2015.

6 Marsden-Smedley JB, Catchpole WR. *Fire behaviour modelling in Tasmanian buttongrass moorlands*. II. Fire behaviour. International Journal of Wildland Fire 1995; 5: 215-228.

7 Sharples JJ, McRae RH, Weber RO, Gill AM. *A simple index for assessing fuel moisture content*. Environmental Modelling & Software 2009a; 24: 637-646.

8 Sharples JJ, McRae RH, Weber RO, Gill AM. *A simple index for assessing fire danger rating*. Environmental Modelling & Software 2009b; 24: 764-774.

9 Sharples JJ, Matthews S. *Evaluation of some simplified models for predicting the moisture content of fine, dead fuels*. In: Chan, F., Marinova, D. and Anderssen, R.S. (eds) MODSIM2011, 19th International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand, December 2011, pp. 242 – 248.

10 Sharples JJ, McRae RH. *Evaluation of a very simple model for predicting the moisture content of eucalypt litter*. International Journal of Wildland Fire 2012; 20:1000-1005.

11 Sharples JJ, McRae RHD. *A fire spread index for grassland fuels*. In: Piantadosi, J., Anderssen, R.S. and Boland J. (eds) MODSIM2013, 20th International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand, December 2013, pp. 249–255.