NATURE ABHORS CURVATURE - FIRES INCLUDED!

MODELLING SPOT FIRE COALESCENCE

Jason Sharples[1], James Hilton[2], Claire Miller[2], Andrew Sullivan[3]

[1] School of Physical, Environmental and Mathematical Sciences, UNSW Canberra

[2] CSIRO Computational Informatics

[3] CSIRO Ecosystem Sciences

SPOTTING CAN BE THE DOMINANT FIRE PROPAGATION MECHANISM DURING TIMES OF EXTREME FIRE WEATHER. SPOT FIRES CAN MERGE AND COLLAPSE ON ONE ANOTHER CREATING REGIONS OF DEEP FLAMING, WHICH PRODUCE VIOLENT PYROCONVECTION. UNDERSTANDING AND MODELLING THE INTRINSIC DYNAMICS OF SPOT FIRE COALESCENCE IS AN IMPORTANT STEP IN PROVIDING WAYS OF MITIGATING THE EFFECTS OF EXTREME FIRES.

SPOT FIRE COALESCENCE

When multiple embers start spot fires ahead of the main region of a bushfire, they can spread and coalesce as depicted below in Figure 1. Ultimately, the coalescence of the individual spot fires will occur in one of two ways:

- Fire line merging, or
- Fire perimeter collapse

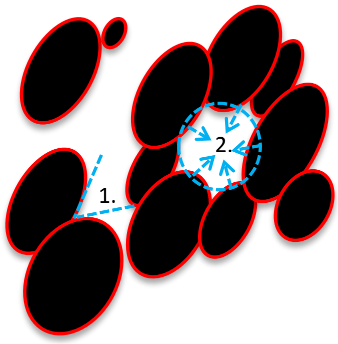

Figure 1: Schematic representation of coalescing spot fires. Fire line merging is taking place at point 1, while perimeter collapse is taking place at point 2.

In each of the two cases depicted in Figure 1 the fire can exhibit abrupt increases in rate of spread – these arise as a consequence of dynamic fire-fire and fire-atmosphere interactions.

MODELLING FIRE COALESCENCE

The modelling of fire coalescence can be reduced to consideration of the two cases of a merging V-shaped fire and a 'ring' of fire burning in on itself. These two cases have recently been considered by international researchers, who have used complex coupled fire-atmosphere models, or models involving detailed radiation budgeting to account for the dynamic behaviour of the fires in these cases.

Our approach to modelling these phenomena is more geometric – we invoke fire line curvature as a factor influencing the fire's development in these two (and other) cases.

CURVATURE-BASED FIRE SPREAD MODEL

We model the growth of a fire with a rate of spread that depends on fire line curvature. The model is implemented in terms of a level-set function ϕ, which satisfies the governing nonlinear partial differential equation:

$$\partial_t \phi + \alpha \nabla^2 \phi + N(\phi) = 0,$$

where

$$N(\phi) = \alpha \frac{\nabla \phi}{|\nabla \phi|} \cdot \nabla(|\nabla \phi|) + \beta |\nabla \phi|.$$

In this model the curvature dependence on rate of spread is assumed to follow a simple linear relationship – more sophisticated curvature dependence could (and will) be considered.

The model runs as a two-dimensional model in a very computationally efficient way. All of the complicated (and computationally demanding) processes have been absorbed into the fire line curvature, which serves as a simple proxy for their effects.

The curvature dependence in the model causes parts of the fire line which curve in on themselves (like 1 and 2 in Figure 1) to preferentially smooth out in a dynamic manner.

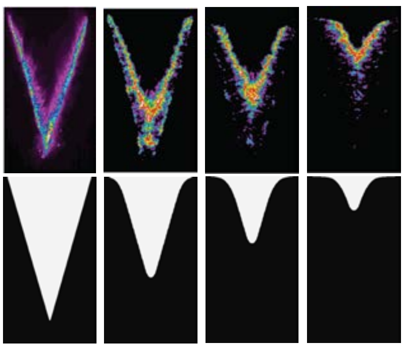

Figure 2: Infrared imagery of a V-shaped fire merging (top). Curvature-based fire spread model (bottom)

RESULTS

Figure 2 shows the output of the curvature-based model compared with infrared imagery of a laboratory-scale fire . As can be seen, the model provides a good qualitative fit with the observational data. The quantitative agreement is also reasonably good, with the curvature-based model able to accurately reproduce the acceleration of the point of intersection of the two fire lines.

Figure 3: Aerial photograph of an experimental grassfire (left). Output from the curvature-based fire spread model (right). Photo credit: Miguel Cruz & David Nichols

The model has also been successfully applied to larger-scale experimental fires as can be seen in Figure 3. This figure shows an experimental grassfire (Ballarat 2014) on a 40m×40m plot alongside output from the curvature-based model. The experimental burn was initiated as a broad V-shaped fire line. The curvature-based model was able to accurately reproduce the evolution of the fire perimeter, which involved a significant dynamic element. The same was not true for the model that did not incorporate any curvature effect.

CONCLUSIONS AND FURTHER WORK

Preliminary results using a curvature-based model are promising. The curvature term seems to act as a good proxy for more complicated dynamic effects. Future work will consider the collapse of ring fires and quantification of the contributions of radiation and convection to the overall curvature effect.

Email: **j.sharples@unsw.edu.au**

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