A model for the intersection of wildfires and erosive storms in space and time

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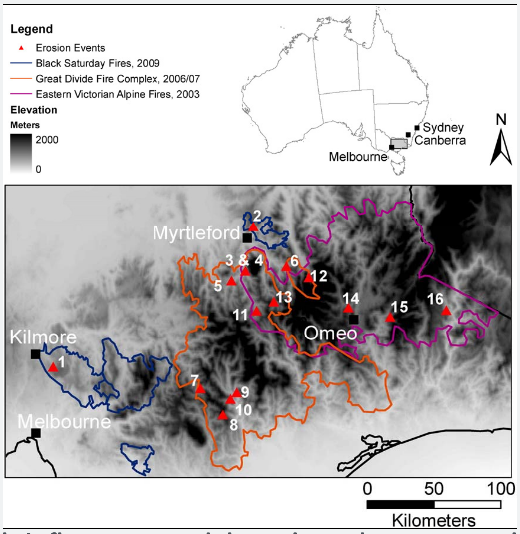
Background

Post-fire debris flows and other extreme erosion events strip forested ecosystems of soil and nutrients, damage infrastructure such as roads and buildings, and can contaminate water reservoirs for long periods. Debris flows result from the spatial and temporal intersection of burnt areas and storms of sufficient intensity to initiate these erosion processes. The spatial and temporal properties of burnt areas and storms affect the probability of an intersection occurring.



Debris flows occurred throughout the eastern uplands of Victoria following recent wildfires. The figure outlines wildfires in 2003, 2007 and 2009 and the red triangles indicate the location of debris flows. All debris flows occurred in steep upland catchments in dry Eucalyptus forest and were triggered by convective thunderstorms.

Most research to date focus on predicting erosion response given a rainfall input once a fire has occurred. However, over long time scales the risk associated with post-fire erosion across the landscape is to a large degree driven by the intersection of wildfires and high intensity rainfall events. The continued development of post-fire erosion models should therefore be coupled with research that aims to predict the landscape scale processes that provide the conditions required for post-fire erosion to occur in the first place. This is particularly important when both fires and rainfall regimes are changing in response to climate change and land management strategies.

Model development

In order to understand the implications of changed fire and rainfall regimes we need to reduce complexity and identify an appropriate mathematical model to represent the dominant elements in the system. We represent our system as a Poisson process (germ and grain model) by making the following assumptions :

- Wildfires occur randomly in time and space and are of a random size.
- Erosive storm cells occur randomly in time and space and are of a random size.

It can be shown that the expected area of intersection between storms and recently burned areas (*E IIAII)* can then be estimated from the following expression:

$$E\|A\| = \Omega(1-e^{-\lambda\alpha})(1-e^{\mu\beta})$$

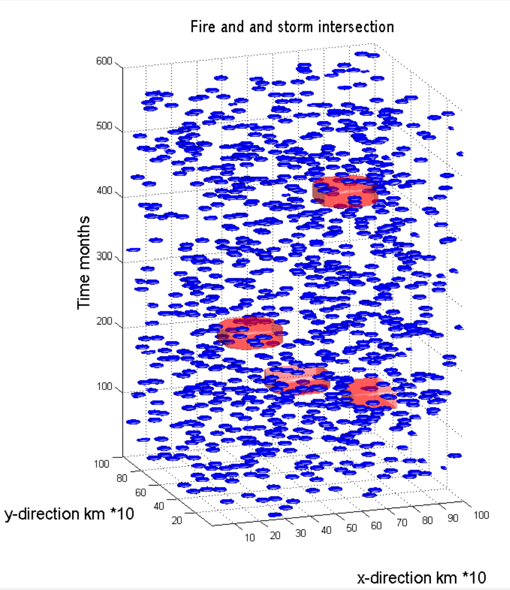
Where…

λ = fire event rate (per unit area and unit time)

μ = storm event rate (per unit area and unit time)

α = E[||fire event||] (in km^2 * time)

β = E[||rainfall event||] (in km^2 * time)



This figure illustrates how the model represents fires (red discs) and storms (blue discs) in space and time. It is a 50 year simulation in a 1000 X 1000 km grid using a constant fire size and storm size. The fire effect (height of the disc) is active for two years while storms only last 30 minutes. The areas where red and blue disc overlap should be proportional to the number of high magnitude erosion events that are likely to occur across the landscape.

Model parameters

The frequency and size distribution of storms and fires can be quantified from existing data sets.

We used *fire history data* from Victoria to derive the average frequency and size of fires > 100 hectares.

Region	Area (km^2)	Data range	λ (fires yr^{-1} area^{-1})	α Mean fire size (km^2)
VIC	237629	1972-2009	1.18 * 10^{-4}	55

Source: Victorian Department of Sustainability and Environment

We used *rainfall intensity-frequency-duration curves from Bureau of Meteorology and depth area reduction factors (DARF)* for convective storm cells to derive the frequency and size of storms that exceed the estimated 30-minute rainfall intensity thresholds of approx 35mm h^{-1} (Nyman et al. 2011).

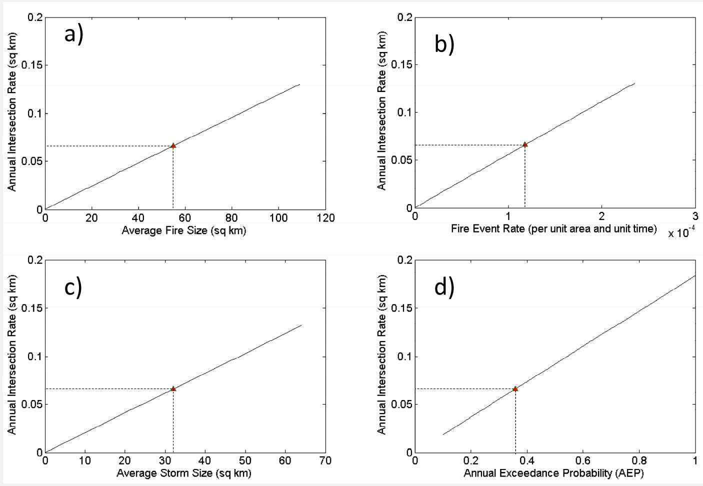
Region	Data range	μ (storms yr^{-1} area^{-1})	β Mean storm size (km^2)
NE Victoria	1969-2011	1.12*10^{-2}	32

Source: Bureau of Meteorology

Model outputs

The annual rate of intersection , *E II A II,* given these parameter estimates is approximately 7ha. In some years the intersection is zero, other years it will be higher. Both the variance and the distribution of *E II A II* can be derived using this modeling approach and is part of future work.

The sensitivity of the system to parameter inputs can be explore by plotting the intersection rate for a range of input variables.



The intersection rate as a function of a)Fire Size, b) Fire Event Rate, c) Storm Size and d) Storm Annual Exceedance Probability. The red marker indicates the actual parameter value and the corresponding intersection rate.

References:
Nyman, P., G. J. Sheridan, et al. (2011). "Evidence of debris flow occurrence after wildfire in upland catchments of south-east Australia." Geomorphology **125(3): 383-401.**