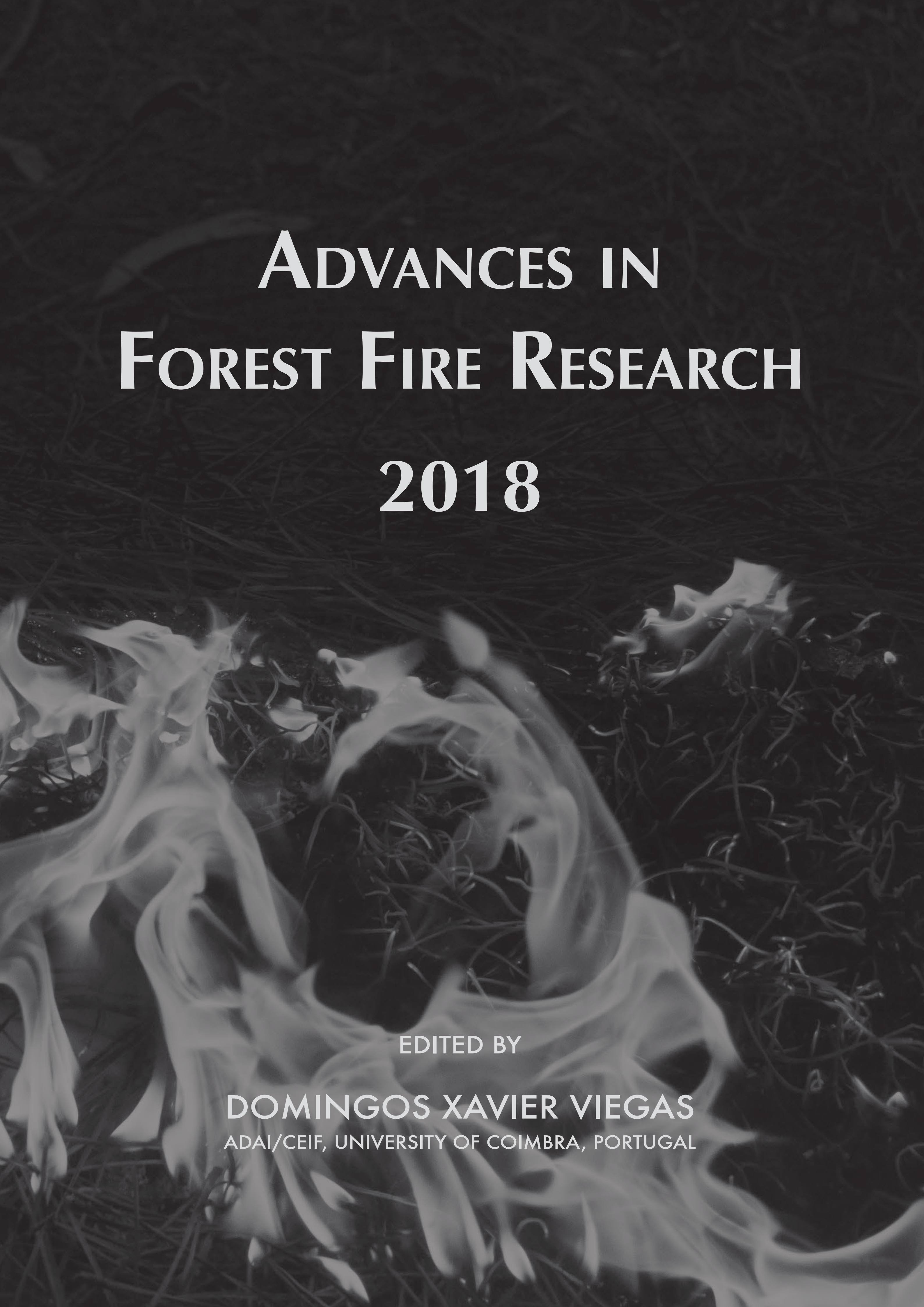

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Short contribution – Fire Risk Management

The role of fire size, geometry, and intensity, in “extreme” plume development

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Abstract

Fire spread associated with violent pyrogenic convection is highly unpredictable and is difficult to suppress. Wildfire-driven convection may generate cumulonimbus (storm) clouds which are also known as pyrocumulonimbus (pyroCb). Research into such phenomena has tended to treat the fire on the surface and convection in the atmosphere above as separate processes.

This research investigates the relationship between the characteristics of the surface (i.e. the fire) - its shape, size and intensity - and the resultant convective plume. This is achieved using a coupled fire-atmosphere model (the Weather Research and Forecast model (WRF)) to identify the combined effects of the fire behaviour and atmospheric structure on the occurence of pyroCb events. This is achieved with idealised model runs with a static heat source of variable dimension and intensity in order to examine the plume's sensitivity to the size and intensity of the fire, and the stability of the atmosphere in which it develops. It also considers the role of geometry of the spatial expanse specifically, as large areal fires (so-called "deep flaming" events) have been associated with the development of pyroCb. Moisture from either the fuel or combustion is not included in the surface fluxes at this point in the study.

Initial results indicate that both the size and intensity of the fire are the variables which control the height to which the pyroconvective plume may rise. It also suggests that given a large enough fire source (deep flaming), these factors are the key determinanats of whether the plume will couple with the atmosphere and that the atmospheric stability may not be as influential in the development of violent pyroconvection if deep flaming is occuring.

One of the metrics used to determine the pyroconvective potential of a plume is the total energy released, which is a function of the fire's area across the ground and intensity of the heat. This research also takes into account the shape of the fire by investigating the ratio between the perimeter of the fire and the area it encompasses. Our research determines how the the shape of the fire affects the height of the plume by comparing circular, square and rectangular fires of varying length and width which represent the difference between firelines and areal fires. This sensitivity study of fire geometry reveals that the perimeter/area ratio influences the amount of entrainment that the plume experiences and therefore the height to which the plume rises before it loses buoyancy. These results will be used to aid in the prediction of blow-up fires and may be useful in determining where fire agencies deploy their limited resources.

Keywords: Wildfire simulation, fire-atmosphere interaction, deep flaming, pyroconvection, pyrocumulonimbus

1. Introduction

The prediction of violent pyroconvection is an important area of research. The particular geometric characteristics of the fire have not been a major consideration until now, and this research seeks to better understand the relationship of the fire - its shape, size and intensity – and the plume it produces.

These areal fires have been shown to occur in several instances in which a pyroCb developed, some Australian examples being; the 2003 Canberra fires (McIntyres Hut and Bendora Dam), 2006 Grose

Valley fire, 2013 Wambelong and Aberfeldy fires. These large spatial fires are known as deep flaming (McRae and Sharples 2014), which may encompass several square kilometres and occur when wildfires experience any (or more) of the following triggers:

- Very strong winds – so the head fire advances more rapidly than the back of the flaming zone;
- Changes in wind direction – so the long flank of the fire is transformed into a fast running head fire;
- Eruptive fire behaviour – where steep slopes can cause a fire to accelerate rapidly;
- Vorticity-driven lateral spread – where strong winds and steep terrain interact to rapidly drive a fire laterally, accompanied by downwind spotting (Sharples et al. 2012, Simpson et al. 2013, Simpson et al. 2014); and
- Fire coalescence – including mass spot fires from embers and lightning or merging of fires introduced into the landscape by other means.

As deep flaming has shown itself to be associated with pyroCbs, this study intends to explore this relationship more thoroughly.

1.1. Method

1.1.1. Circular heat sources

Using the WRF, several idealised models were run using three different static cicular heat sources (25 kW m^{-2}, 25 kW m^{-2}, and 100 kW m^{-2}) with radii of 150 m, 500 m, 750 m, 1 km and 1.5 km. All of these were then run in a stable, neutral and unstable atmospheric profile (Fig. 1).

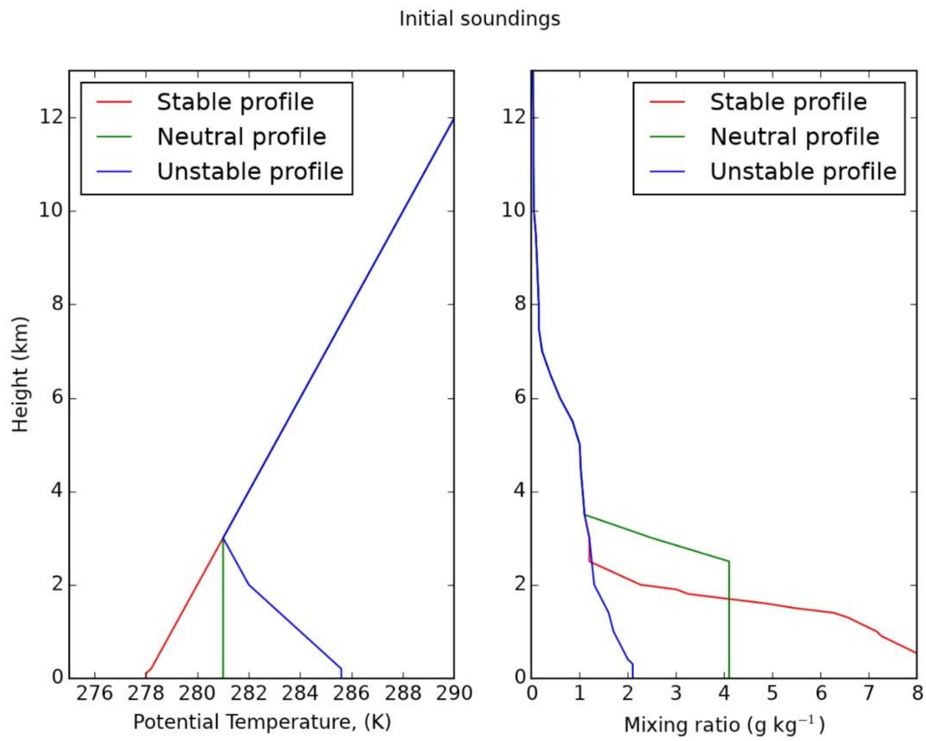

Figure 1 - Input soundings for all model runs of potential temperature in K (left) and mixing ratio in g kg^{-1} (right) for the lowest 13 kms are shown.

Figure 2 shows cross-sections of four of the different size fires after one hour of the simulation with a neutral atmospheric stability. This profile is typical of high fire danger in Australia with a deep mixed layer. As the heat source increases, the height of the cloud base which represents the Lifting Condensation Level (LCL) increases, as does the cloud top (the level of neutral buoyancy). The larger the heat source, the less the effect of entrainment on the convective column, which means that the plume experiences less dilution and more air reaches the LCL, driving convection. It was also found that the higher intensity heat source had a similar effect on the pyroconvection due to warmer air enhancing the convection.

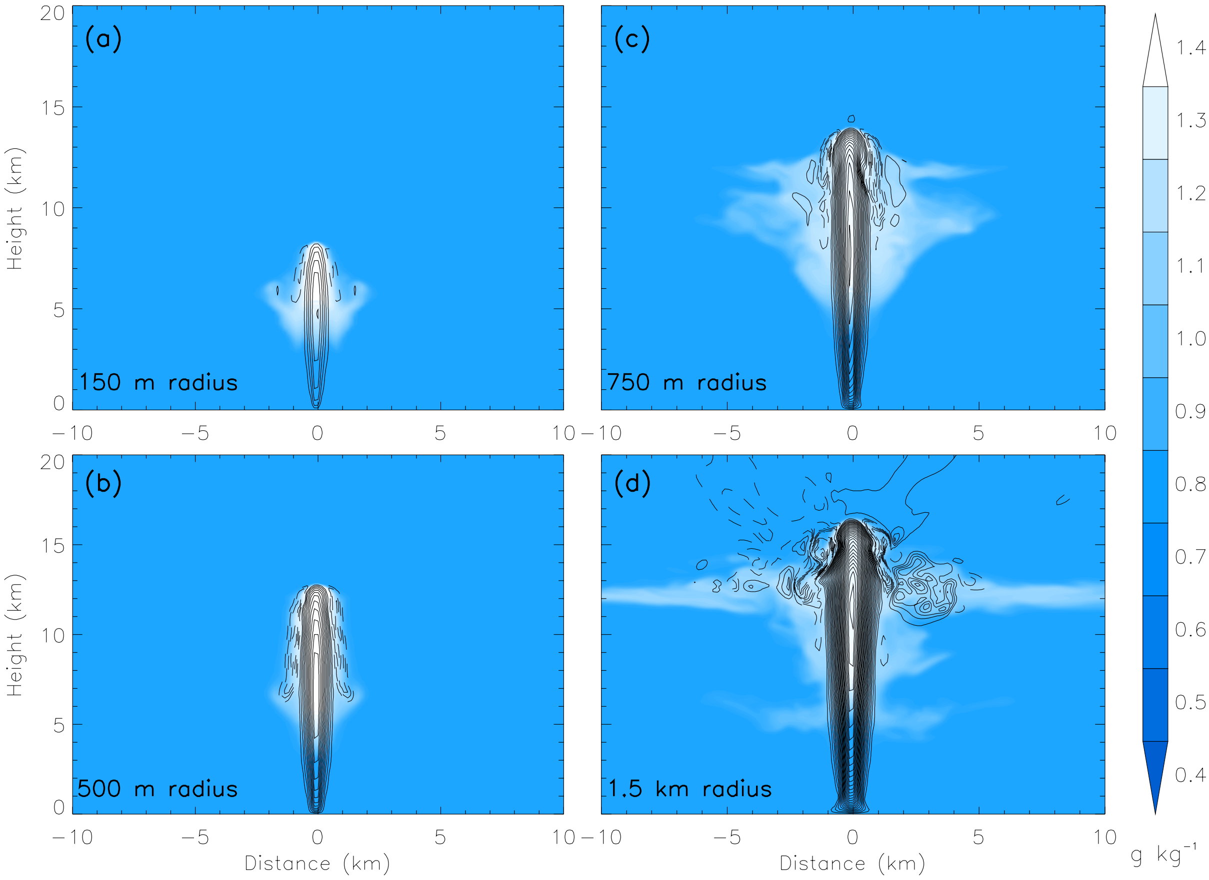

***Figure 2** - Cross-sections of the plume after 1 hour simulation time for (a) 150 m radius, (b) 500 m radius, (c) 750 m radius and (d) 1.5 km radius fires. The blue/white shading represents the cloud mixing ratio in g kg-1 and the solid contours are vertical velocity with solid being positive values and dashed, negative. Contours are every 5 m s-1.*

4.1.1. Other shapes

Figure 3 shows the other shapes of the static heat source that were then run. Each of these fires encompasses the same area as the 1 km radius fire described in the previous section.

Results show that the geometry of the fire dramatically affects the plume height and longevity of the plume. These results have important implications for the prediction of pyroCb and/or towering pyrocumulus formation and will aid fire risk analysts in determining such dangerous conditions.

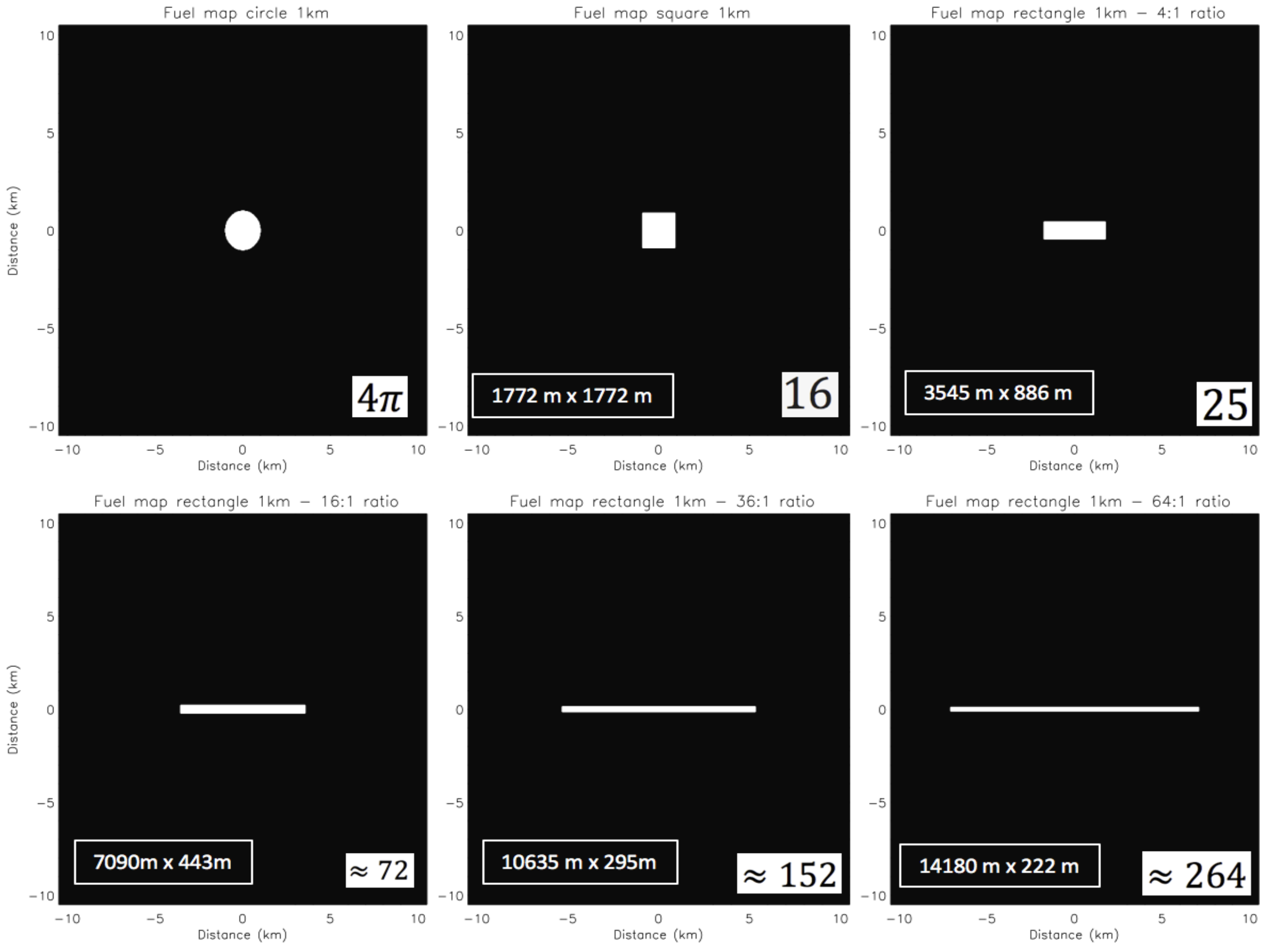

Figure 3 - The fuel maps used to determine how the ratio of the perimeter of the fire to the area affects the plume height. The approximate dimensions (to the nearest metre) are shown in the boxed area and the isoperimetric ratio is shown in the bottom right of each domain.

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