Pyroconvective interactions and dynamic fire propagation

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Photo: Randall Bacon.

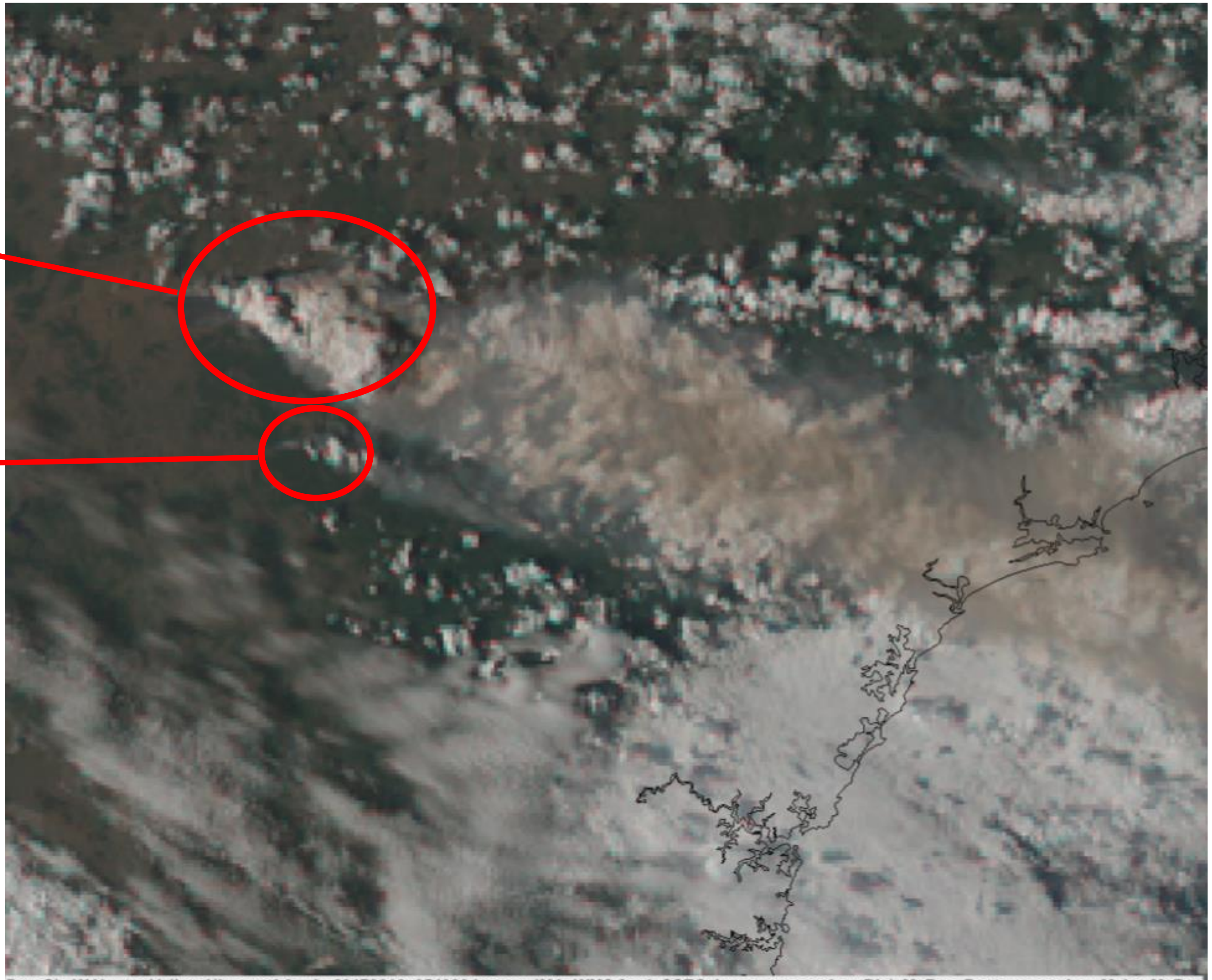
Introduction

- Pyroconvection is the buoyant movement of fire heated air.
- <u>ALL</u> fires are "pyroconvective".

Introduction

Some fires 'go pop'!

While some don't...



PyroCb, W Hunter Valley. Himawari-8 rgb, 20170212_054000 Image: JMA, WMS feed: SSEC, Image processing: Rick McRae, Post processing: Myles McRae

Introduction

- Large plume-driven wildfires are among the most destructive and unpredictable of all natural hazards.

- A prerequisite for the development of the extreme pyroconvection associated with these fires is the existence of a large area of active flaming – referred to as ***deep flaming***.

- See for example:

  Taylor et al. (1973): *Journal of Applied Meteorology*, 12.

  Palmer (1981): *Atmospheric Environment*, 15.

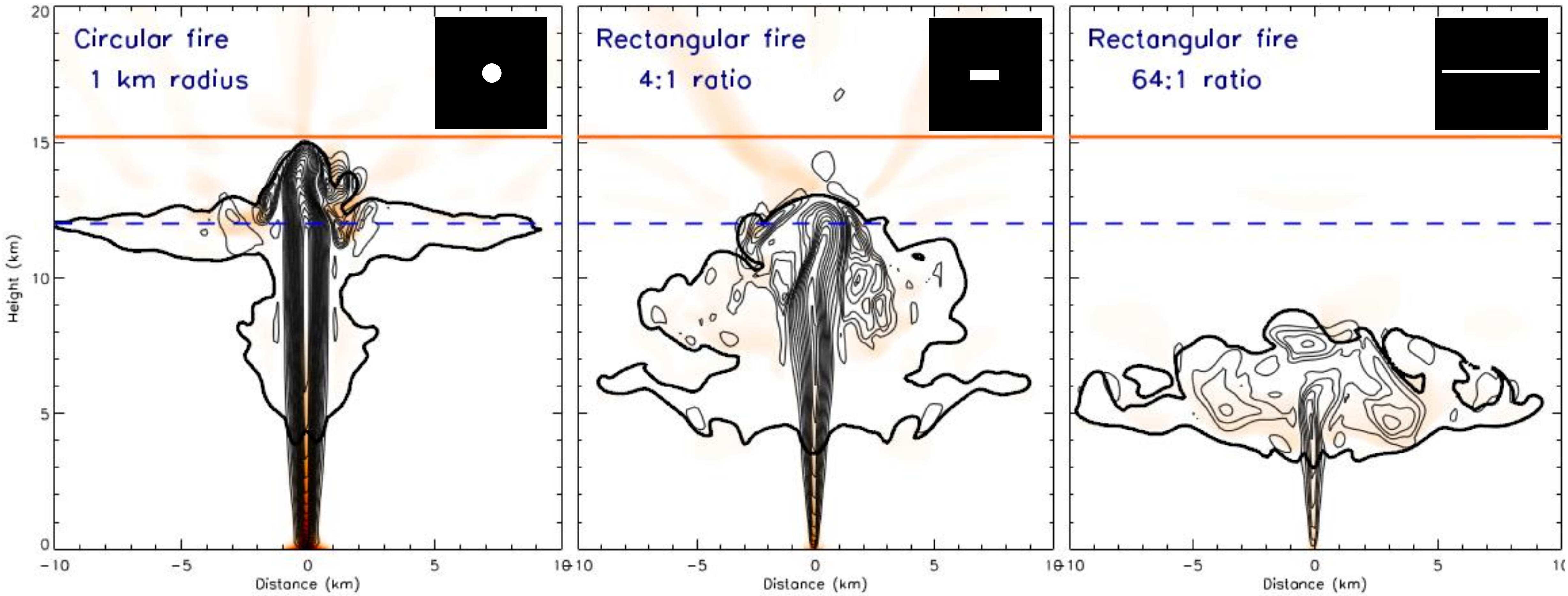
  Brode & Small (1986): In - *The Medical Implications of War*, National Academic Press.

  Finney & McAllister (2011): *Journal of Combustion*, 2011.

  McRae et al. (2015): *Natural Hazards and Earth System Sciences*, 15.

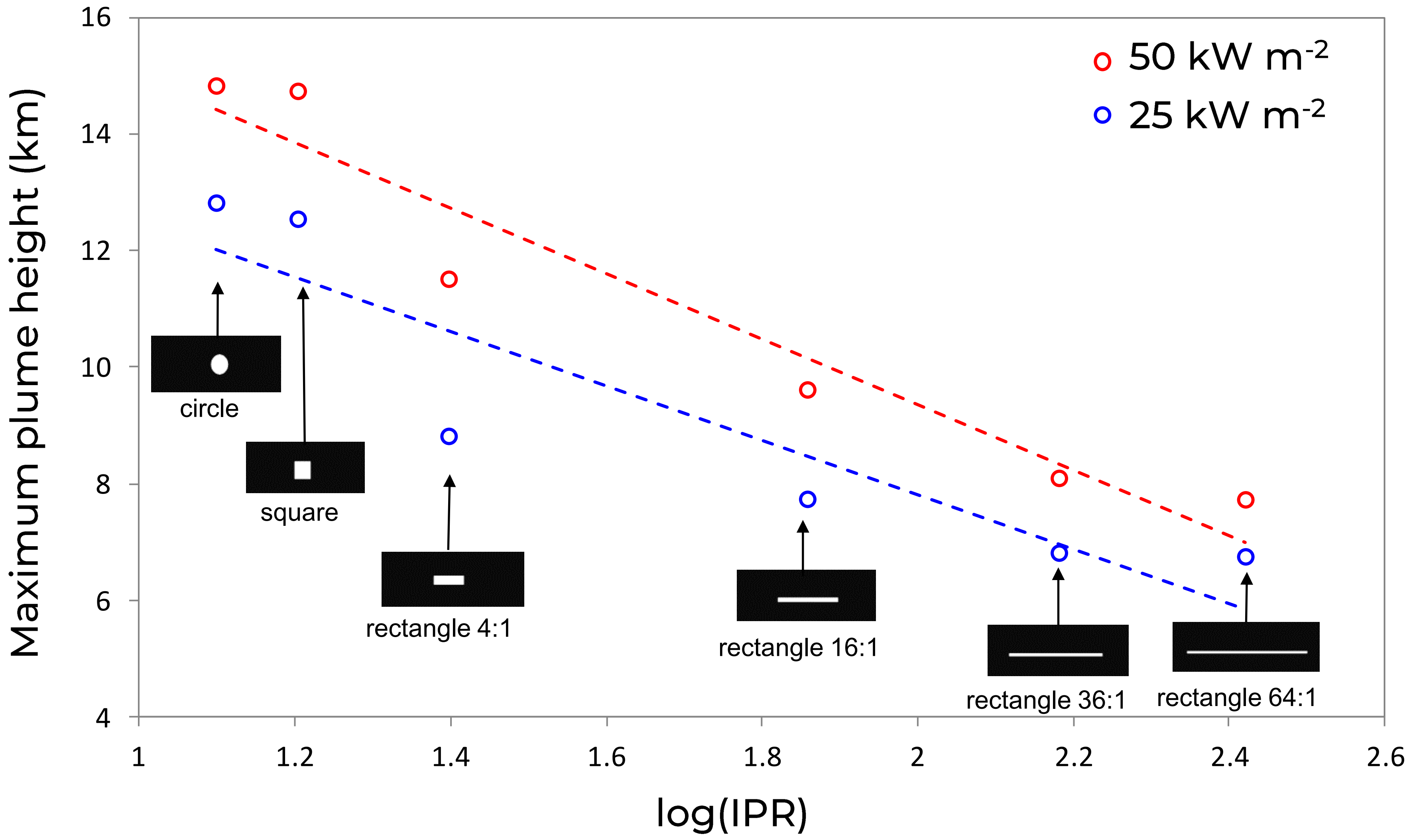
  Badlan et al. (2017): *22nd International Congress on Modelling and Simulation*.

Deep flaming and pyroconvection



All fires have the same total energy release.

Deep flaming and pyroconvection



- Different total energy release leads to a difference of 1-2 km in max plume height.
- Different geometric configuration leads to a difference of 6-7 km in max plume height..

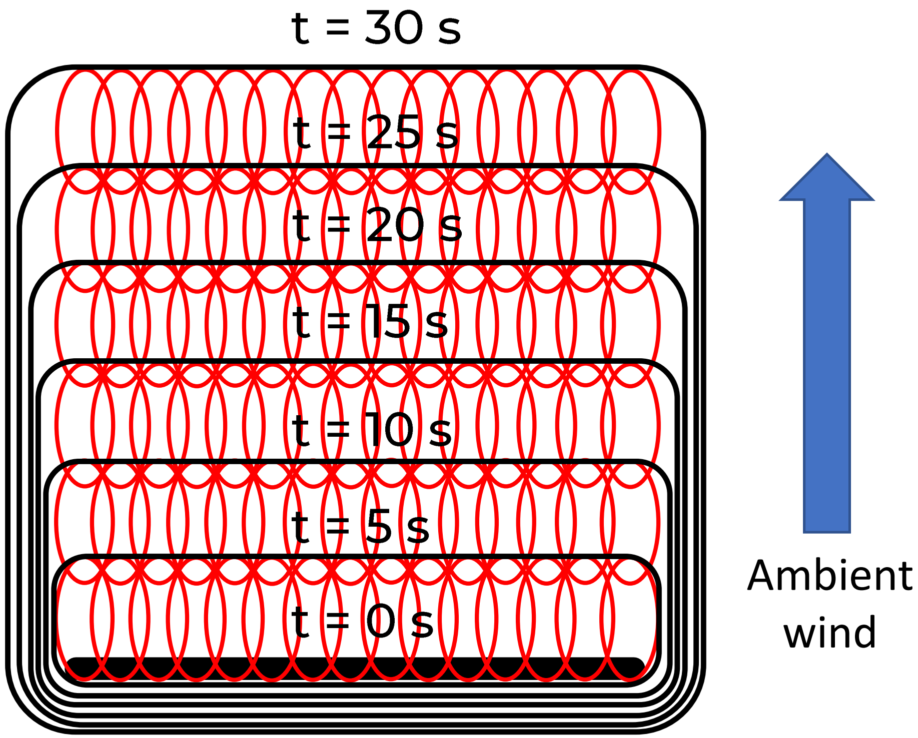
Deep flaming and pyroconvection

- Deep flaming events are associated with dynamic fire behaviours, driven by pyroconvective interactions, and typically involve mass spotting and spot fire coalescence.

- At the moment, dynamic fire behaviours can only be faithfully simulated using coupled fire-atmosphere models – these are computationally expensive; e.g. requiring days on a supercomputer!

- Current operational bushfire simulators cannot account for dynamic fire behaviour – in fact, they can’t even properly account for basic fire behaviours!

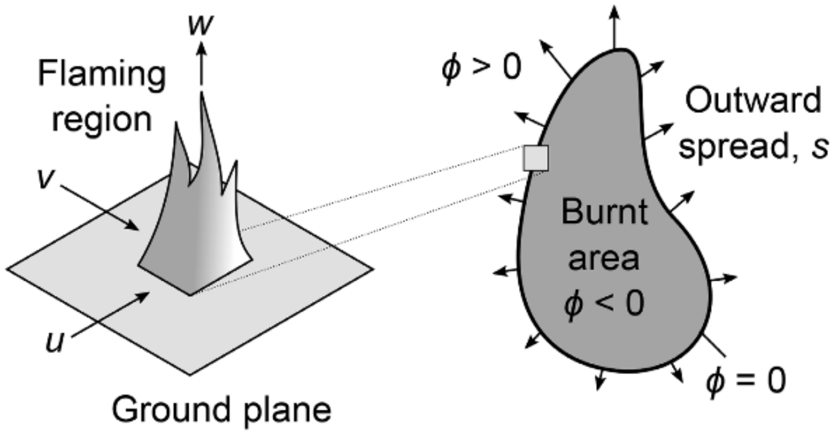
Deep flaming and pyroconvection

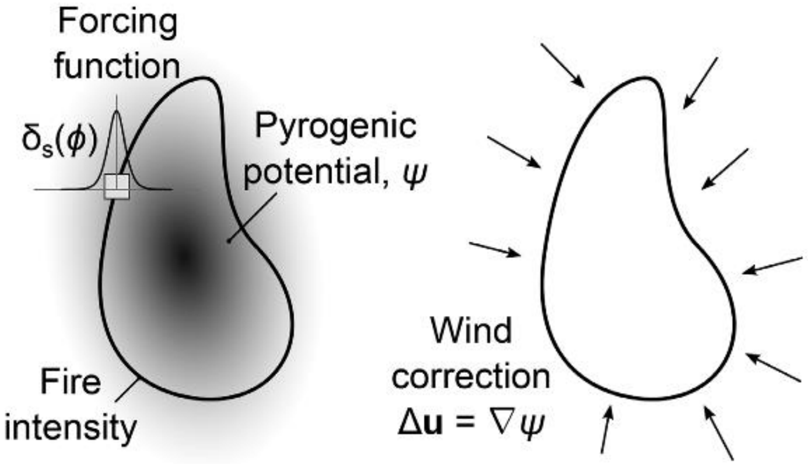


Modelling dynamic fire behaviour

PYROGENIC POTENTIAL MODEL*

LIMITATION: Assumes that pyrogenic wind is irrotational!





$$\frac{\partial\phi}{\partial t} + \beta\|\nabla\phi\| + (\boldsymbol{u}_a + \boldsymbol{U}_p)\cdot\nabla\phi = 0,$$

$$\boldsymbol{U}_p = \nabla\psi, \quad \nabla^2\psi = \rho\left(\frac{\partial w}{\partial z}\right)\int \delta_\varepsilon(\boldsymbol{x}-\boldsymbol{x}_\Omega)d\boldsymbol{x}.$$

The model is ***very*** computationally efficient and fits naturally into the Spark simulation framework…!

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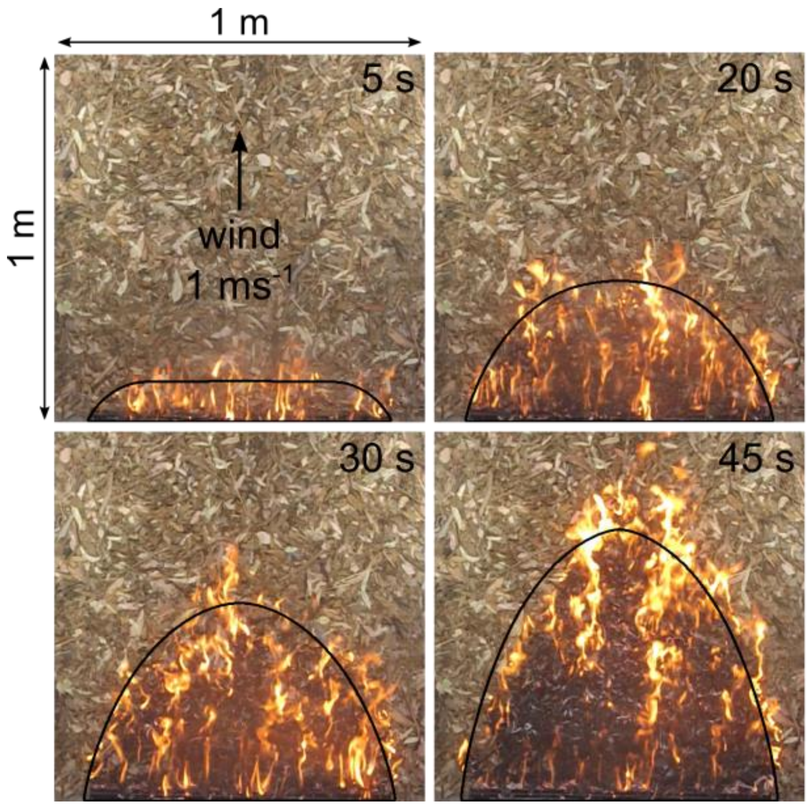
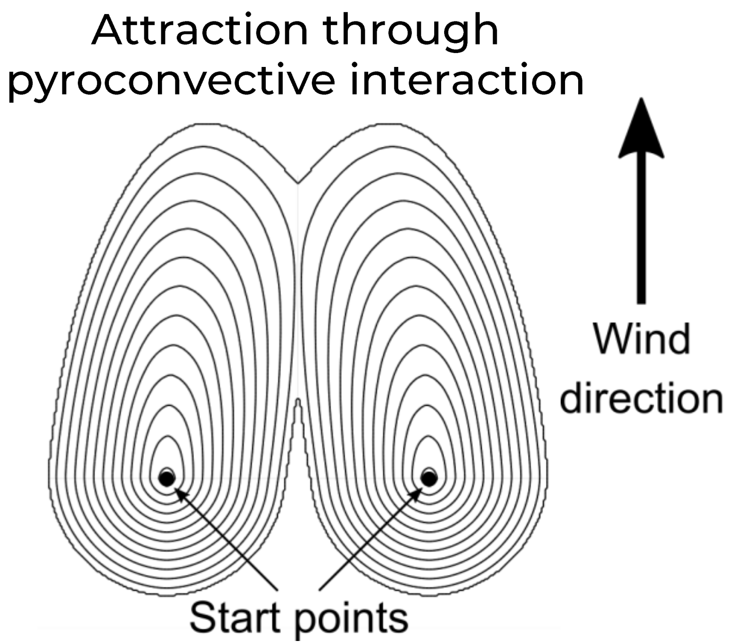
* Hilton et al. (2018) *Environmental Modelling and Software*, 107: 12-24.

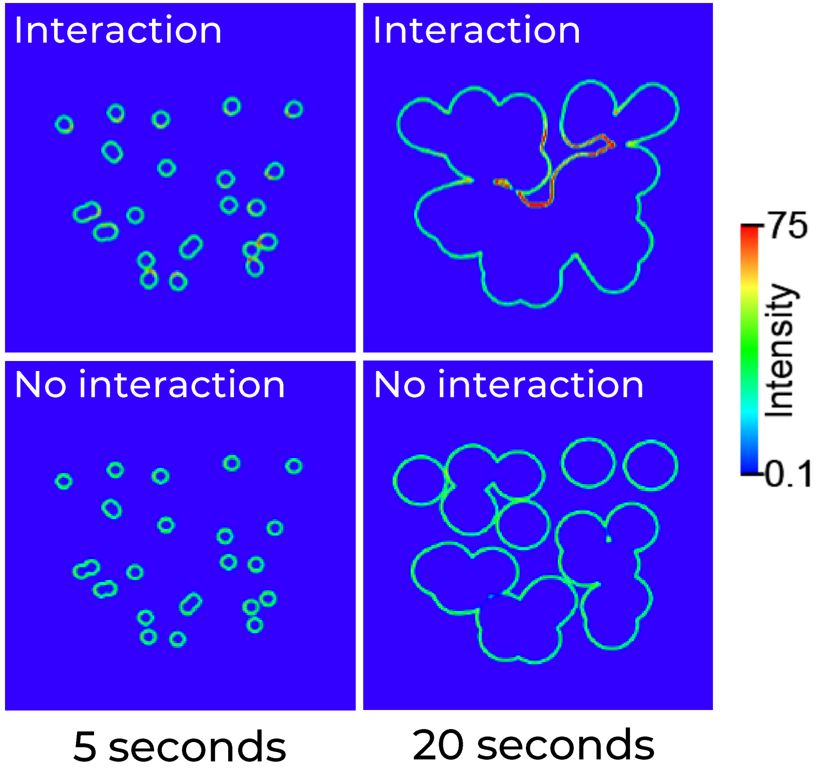
Modelling dynamic fire behaviour



Currently, the pyrogenic potential model is the only two-dimensional fire propagation model that is able to do this!



These considerations are critical for understanding spot fire coalescence and deep flaming!



Modelling dynamic fire behaviour

PYROGENIC POTENTIAL MODEL

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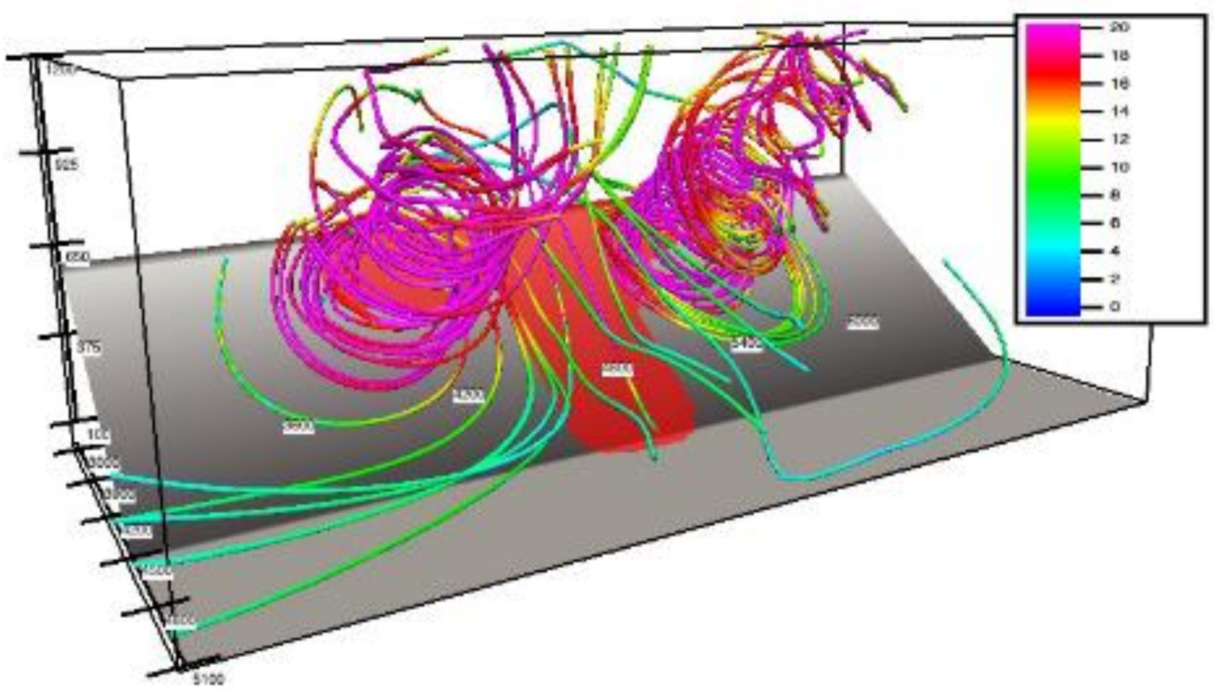

This means that the pyrogenic potential model will not be able to model some dynamic modes of fire propagation, such as vorticity-driven lateral spread…!!

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Modelling dynamic fire behaviour

PYROGENIC POTENTIAL (NEAR-FIELD) MODEL

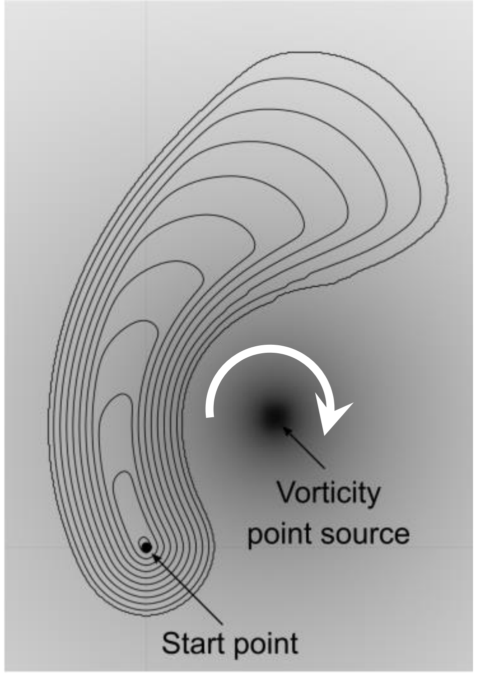
The Helmholtz decomposition tells us that any sufficiently smooth, rapidly decaying vector field can be expressed as the sum of an irrotational part and a solenoidal part, which can be expressed in terms of a scalar potential ψ and a vector potential $\boldsymbol{\chi}$.

$$\boldsymbol{U}_p = \nabla\psi + \nabla \times \boldsymbol{\chi}.$$

$$\nabla^2\psi = \rho\left(\frac{\partial w}{\partial z}\right)\int \delta_\varepsilon\left(\boldsymbol{x} - \boldsymbol{x}_\Omega\right)d\boldsymbol{x},$$

$$\nabla^2\boldsymbol{\chi} = \boldsymbol{\omega},$$

$$\frac{\partial\phi}{\partial t} + \beta\|\nabla\phi\| + \left(\boldsymbol{u}_a + \boldsymbol{U}_p\right)\cdot\nabla\phi = 0.$$



We have already begun to build this capacity into the Spark simulation framework.

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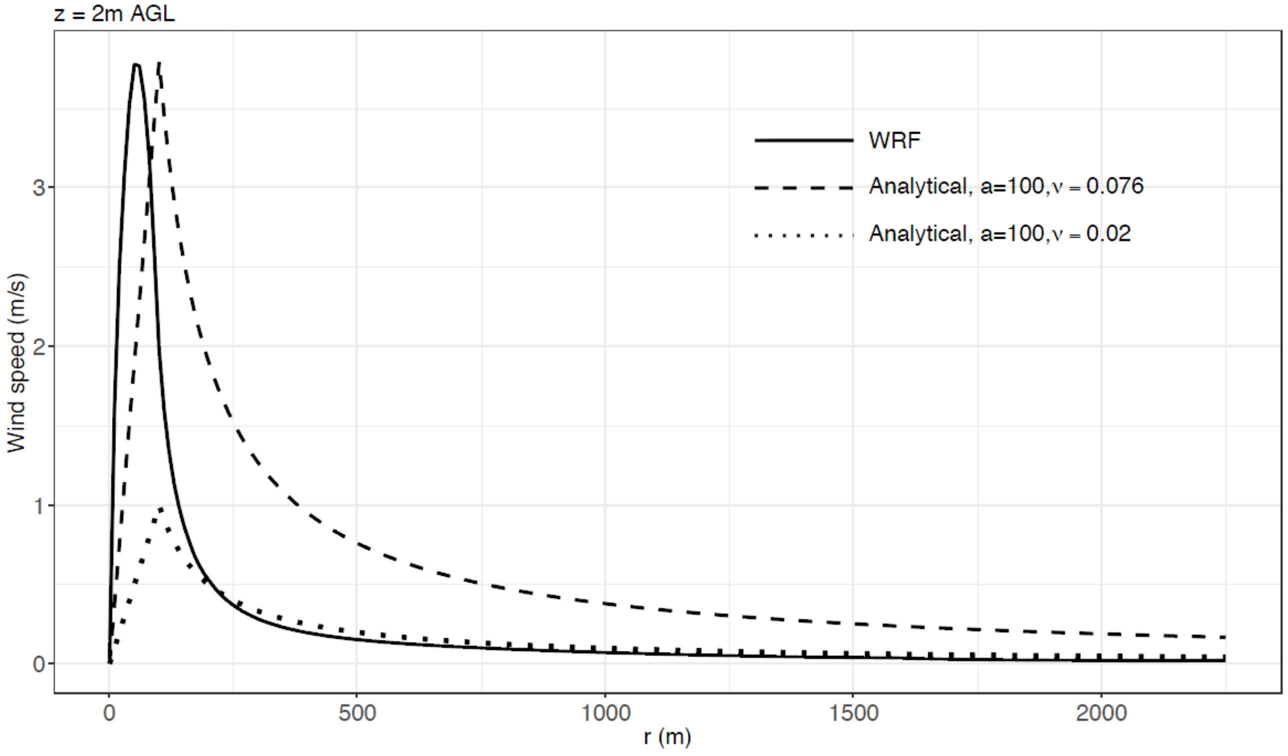
Future research directions

PYROGENIC POTENTIAL (NEAR-FIELD) MODEL

1. Use the near-field modelling technique to simulate vorticity-driven lateral spread.



2. Compare the near-field technique to coupled fire-atmosphere model output for simple, representative scenarios; e.g. a circular heat source.

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Summary

- The geometry and spatial expanse of a fire's flaming zone can be just as, if not more, important than total energy release in driving extreme plume development.
- Dynamic fire behaviours, which are critical in deep flaming and extreme bushfire development, are mostly driven by pyroconvective interactions.
- Current operational models are unable to account for dynamic fire behaviours, or indeed some very basic behaviours.
- We have developed a simple (first-order), two-dimensional, coupled fire-atmosphere model that is able to accurately simulate some forms of dynamic fire spread.
- Future research will focus on further development of the model, and deeper investigation of how the model performs across various scales and scenarios.