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Dynamic fire propagation and extreme wildfire development

Jason Sharples – School of Science, UNSW Canberra

International Workshop of Wildfire Modeling and AI, March 2025

Photo: ABC News

Modelling ember storms at the WUI

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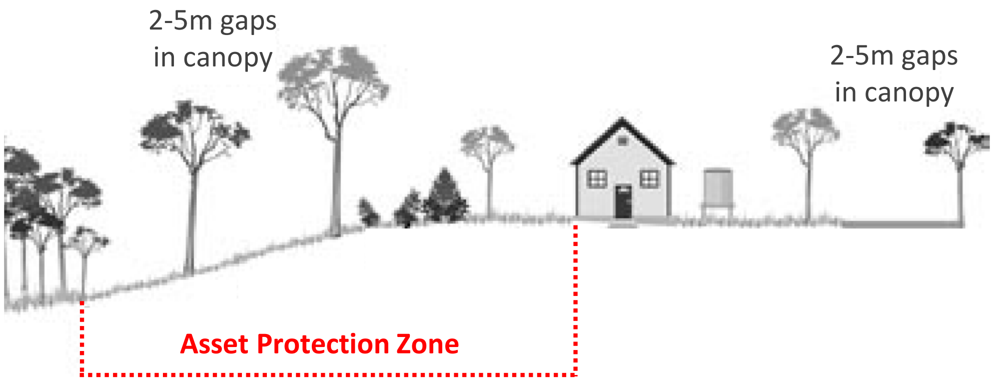
Wildfire risk mitigation at the WUI

In Australia, there are two main approaches to mitigating wildfire risk at the WUI:

- Asset Protection Zones (APZs) – per jurisdiction
- Australian Standard for Building in Bushfire Prone Areas (AS 3959).



Wildfire risk mitigation at the WUI

Asset Protection Zones are designed to provide:

- a buffer zone between a wildfire hazard and an asset;
- an area of reduced fuel that allows suppression of fire;
- an area from which backburning may be conducted; and
- an area which allows emergency services access and provides a relatively safe area for firefighters and home-owners to defend their property.

$$R = 0.012 \times w \times FFDI$$

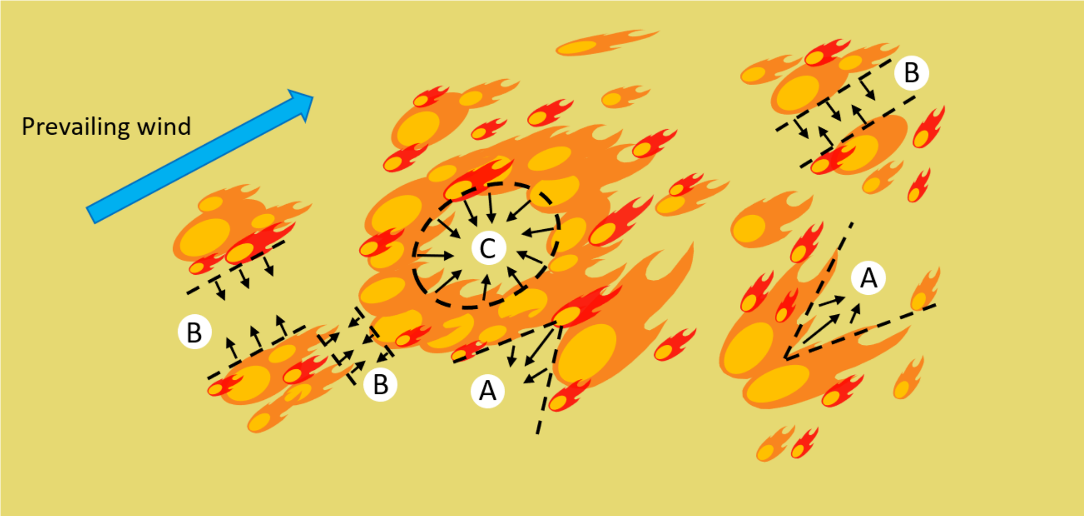
$$I = H \times w \times R$$

$$I = 0.012 \times H \times w^2 \times FFDI$$

However, these formulae are only valid in the special case when a fire is burning with a quasi-steady rate of spread. This fact appears to be grossly underappreciated, despite it first being pointed out by Albini in about 1984…!

Pyroconvective interaction & dynamic fire behaviour

Pyroconvective interactions result in non-steady fire propagation!



Mass-spotting and spot-fire coalescence.

The dashed lines highlight particular examples of non-steady fire propagation:

(A) junction fires;

(B) parallel fire line merging;

(C) perimeter collapse (ring fire).

Green Wattle Fire, NSW 4 Jan 2020
Photo: Levi Roberts, NSW NPWS

Understanding and mitigating the risk

Australian STANDARD

AS 3959:2018
Construction of buildings in bushfire-prone areas

STANDARDS Australia

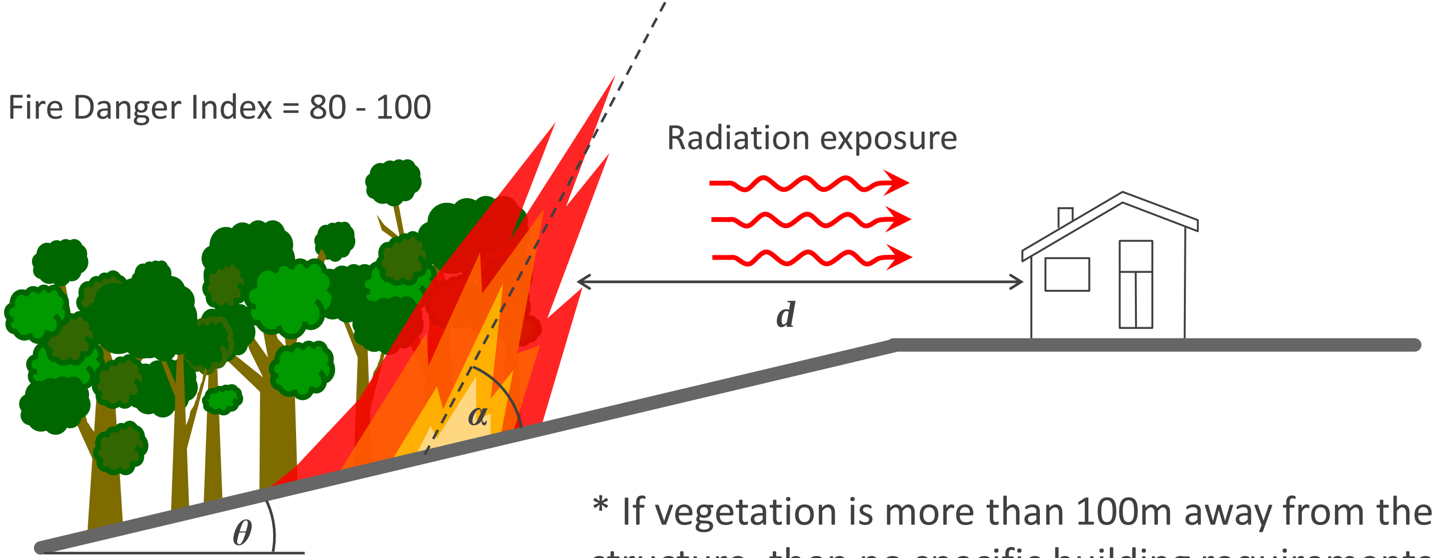
Delivered by SAI GLOBAL

BUSHFIRE ATTACK LEVELS AND CORRESPONDING SECTIONS FOR SPECIFIC CONSTRUCTION REQUIREMENTS

Bushfire Attack Level (BAL)	Classified vegetation within 100 m of the site and heat flux exposure thresholds	Description of predicted bushfire attack and levels of exposure	Construction Section
BAL—LOW	See Clause 2.2.3.2	There is insufficient risk to warrant specific construction requirements	4
BAL—12.5	≤12.5 kW/m^2	Ember attack	3 and 5
BAL—19	>12.5 kW/m^2 ≤19 kW/m^2	Increasing levels of ember attack and burning debris ignited by windborne embers together with increasing heat flux	3 and 6
BAL—29	>19 kW/m^2 ≤29 kW/m^2	Increasing levels of ember attack and burning debris ignited by windborne embers together with increasing heat flux	3 and 7
BAL—40	>29 kW/m^2 ≤40 kW/m^2	Increasing levels of ember attack and burning debris ignited by windborne embers together with increasing heat flux with the increased likelihood of direct contact with flames	3 and 8
BAL—FZ	>40 kW/m^2	Direct exposure to flames from fire front in addition to heat flux and ember attack	3 and 9

Understanding and mitigating the risk

AS3959: Australian Standard for Building in Bushfire Prone Areas…



* If vegetation is more than 100m away from the structure, then no specific building requirements.

Dominant role of embers in propagating the fire…

Ember storm impacting the WUI, Canberra 2003.

Photos: Ned Dawson.

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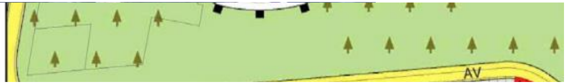
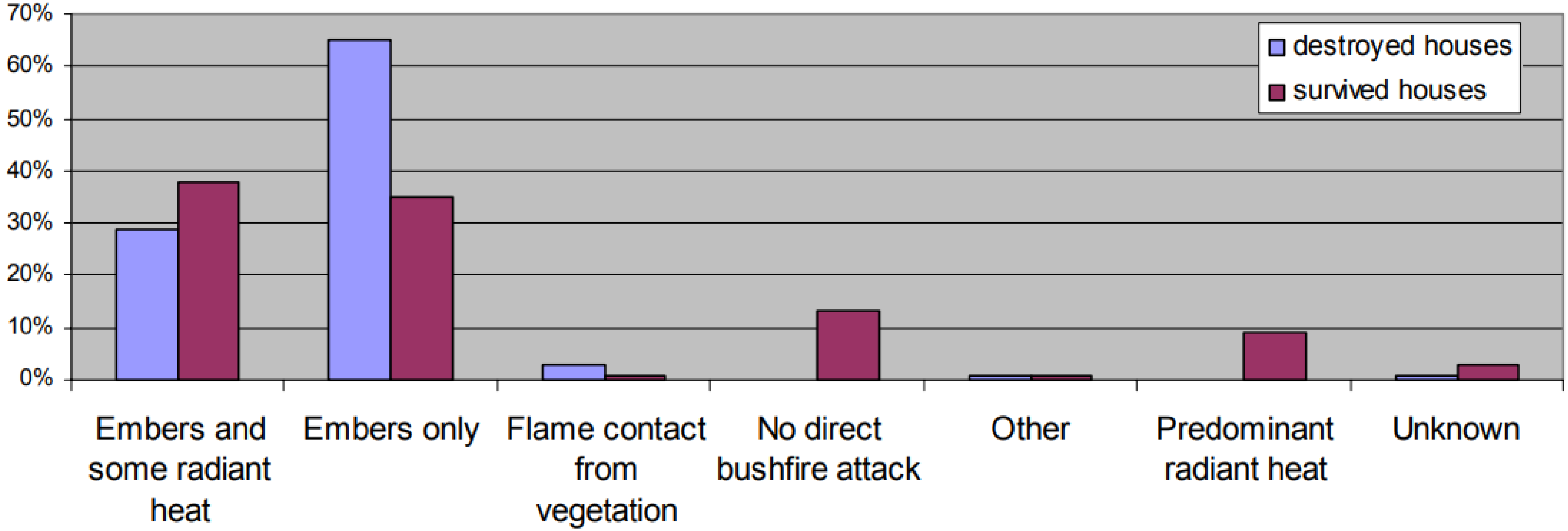
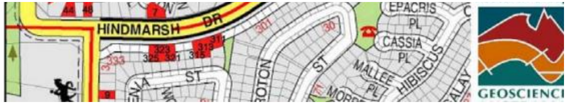
Embers are the leading cause of house loss…







Sources: https://www.canberratimes.com.au/story/6023982/15-years-on-from-canberra-bushfires-a-city-and-its-landscape-are-healing/

Blanchi R and Leonard J. Investigation of bushfire attack mechanisms resulting in house loss in the ACT bushfire 2003. Technical report, Bushfire Cooperative Research Centre (CRC) Report, 2005.

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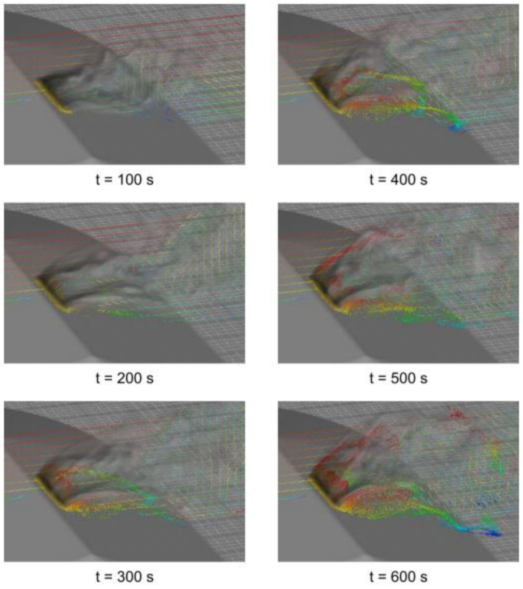
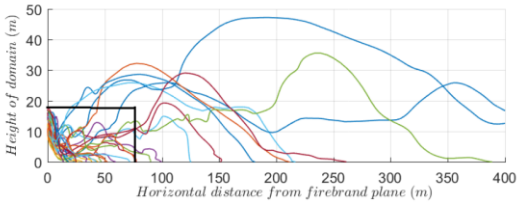
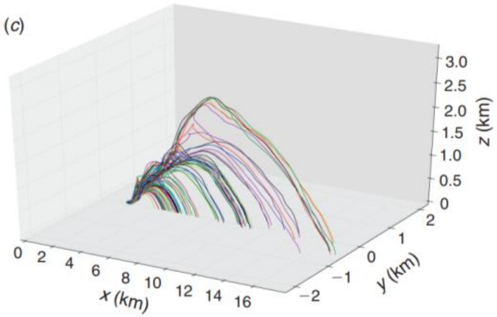
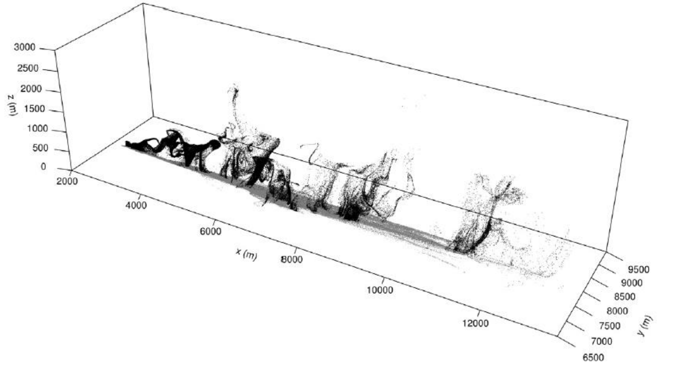
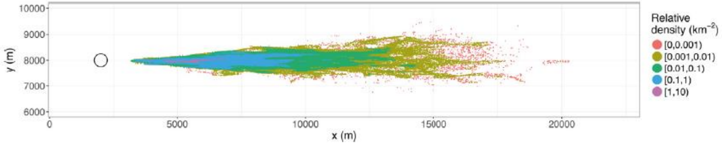
Previous research on embers











Sources:

Hilton et al. (2019) Wind-terrain effects on firebrand dynamics. In International Congress on Modelling and Simulation 2019

Wadhwani (2019) Physics-based simulation of short-range spotting in wildfires. PhD Thesis Victoria University

Thomas et al. (2020) The terminal-velocity assumption in simulations of long-range ember transport. Mathematics and Computers in Simulation

Thurston et al. (2017) The contribution of turbulent plume dynamics to long-range spotting. International Journal of Wildland Fire

Source: https://www.abc.net.au/news/2019-09-09/ember-attack-during-bushfire-on-the-sunshine-coast/11494188?nw=0

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Ember storms: understanding the hazard

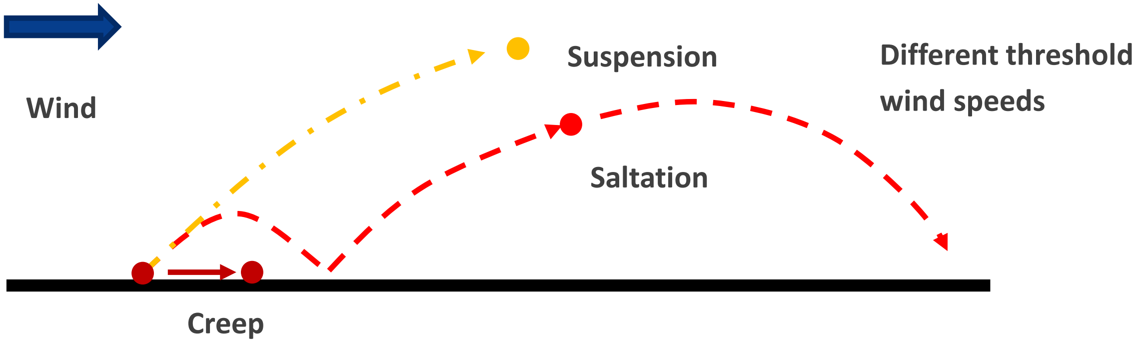
Shifting the focus from **ballistic embers** to **ember storms**…

Ballistic embers

- Lofted hundreds of metres and can travel several kilometres
- Follow quasi-parabolic trajectories

Ember Storms

- Millimetre-scale embers that mostly loft less than 1-2 metres
- Characterised by distinct dynamics involving creep, saltation and suspension

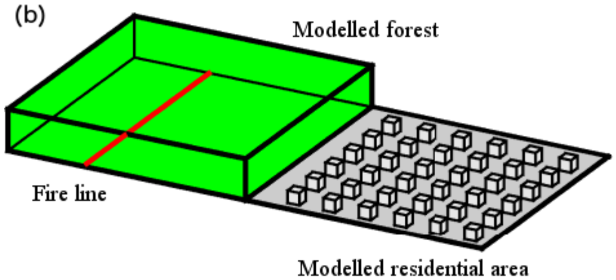


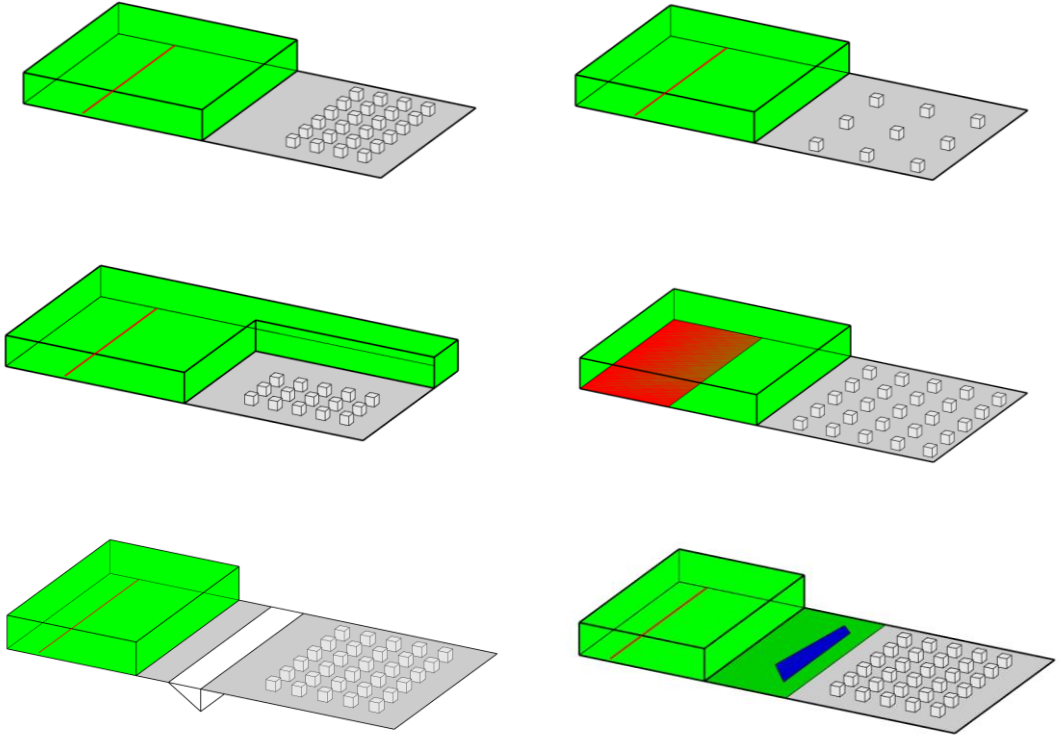
Ember storms: understanding the hazard

The primary objective is to incorporate a model for ember storms in computational simulation that can accurately capture the near-ground behaviour of embers.

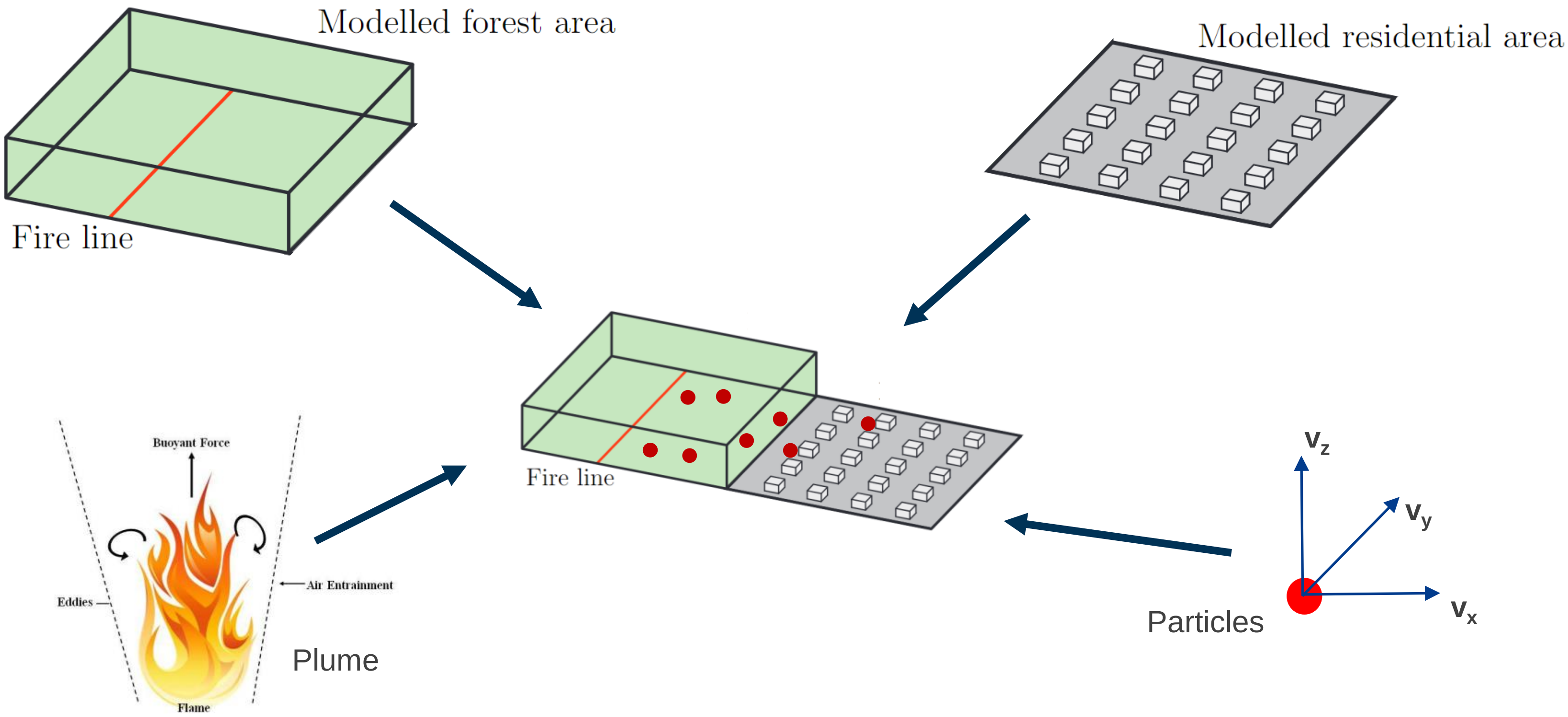
- Role of forest canopy density in causing the onset of an ember storm
- Contribution of different environmental factors (wind speed, temperature, terrain) to the onset of an ember storm
- Effect of varying urban canopy (spacing and height of buildings, obstacles) on the accumulation of embers in an ember storm?

Ember storms: understanding the hazard



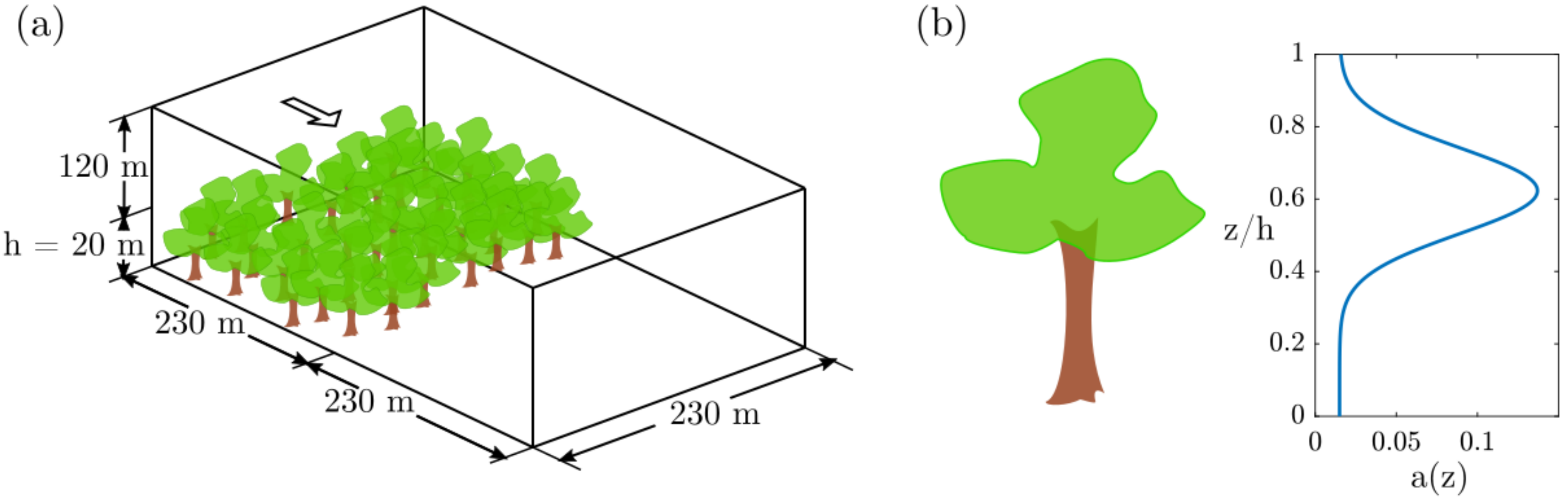


Modelling ember storms at the WUI



* Joint work with Tanvir Saurav (PhD Student) and Dr Duncan Sutherland

Modelling ember storms at the WUI



$$a_f = a \exp\left(- \frac{(z-b)^2}{c^2} \right)$$

* Joint work with Tanvir Saurav (PhD Student) and Dr Duncan Sutherland

Modelling ember storms at the WUI

Drag coefficient

Frontal area

$$F_i = -\rho c_d a_f u_i \|\boldsymbol{u}\|$$

Density

Velocity component

$$\frac{\partial \boldsymbol{u}}{\partial t} + (\boldsymbol{u} \cdot \nabla)\boldsymbol{u} = -\frac{1}{\rho}\nabla p + \nu \nabla^2 \boldsymbol{u} + \frac{1}{\rho}\boldsymbol{F}$$

Modelling ember storms at the WUI

Parallel Particle-In-Cell Library in Fortran ([ppiclF]())

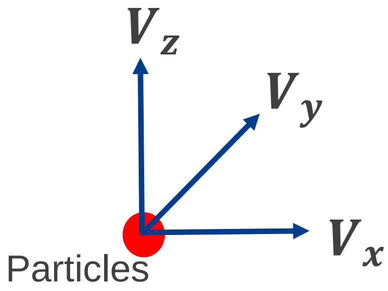
$$\frac{d\boldsymbol{X}}{dt} = \boldsymbol{V}$$

$$m_p \frac{d\boldsymbol{V}}{dt} = \boldsymbol{F}_d + \boldsymbol{F}_c + \boldsymbol{F}_b$$

Collision force

Drag force

Weight



- ➢ 1-, 2-, and 4-way coupling
- ➢ Highly parallelised and can handle millions of particles

*** Joint work with Tanvir Saurav (PhD Student) and Dr Duncan Sutherland**

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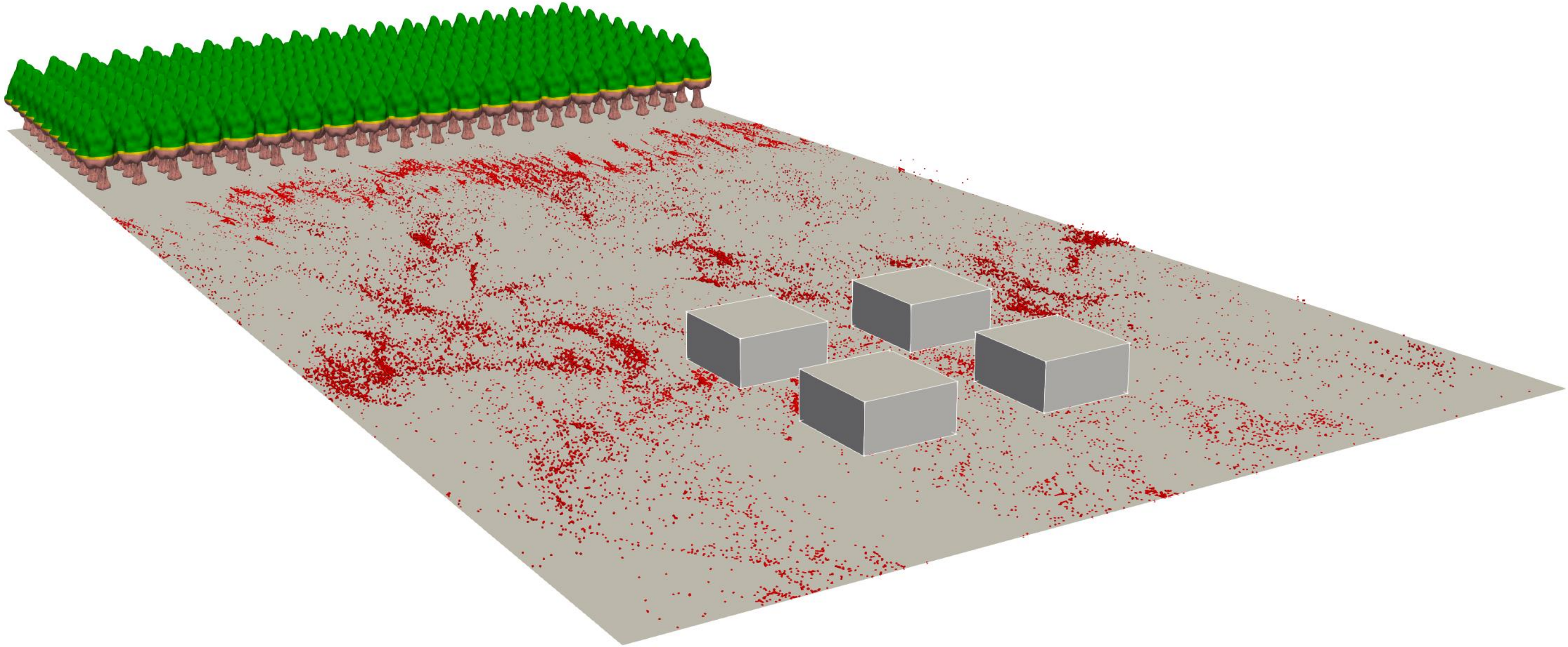
Modelling ember storms at the WUI



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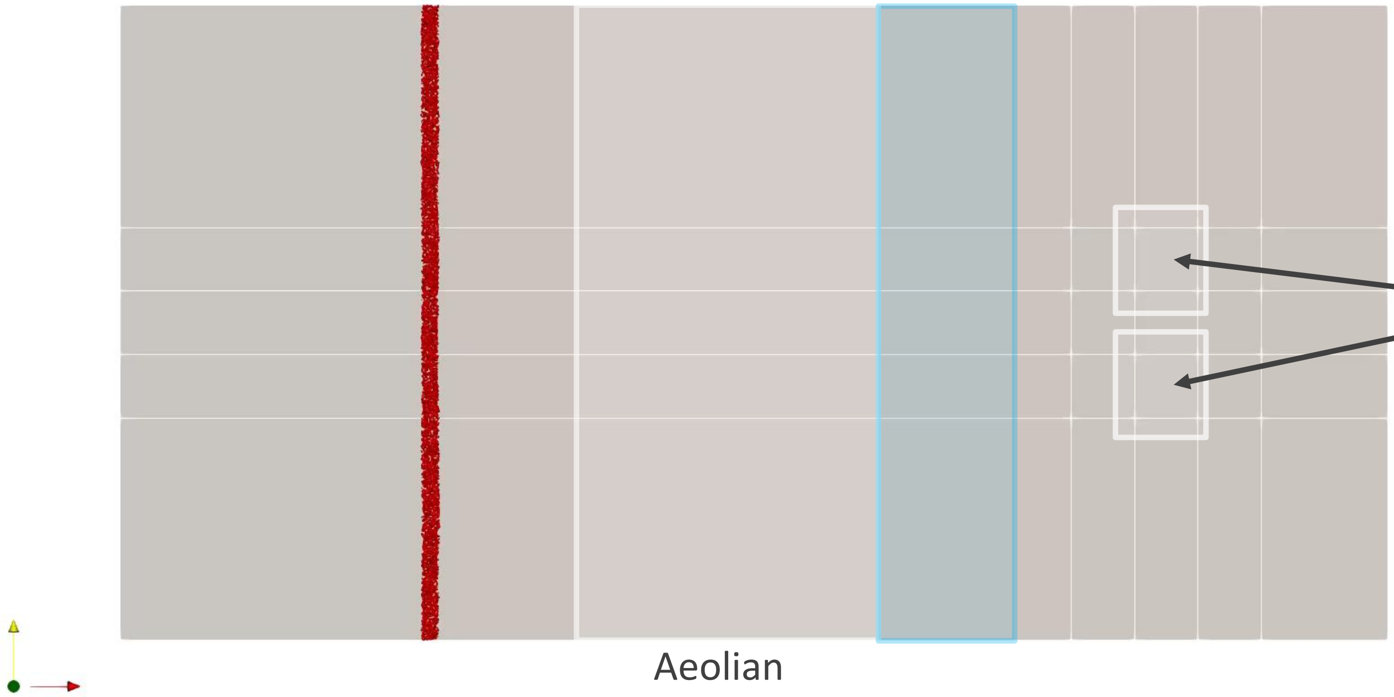

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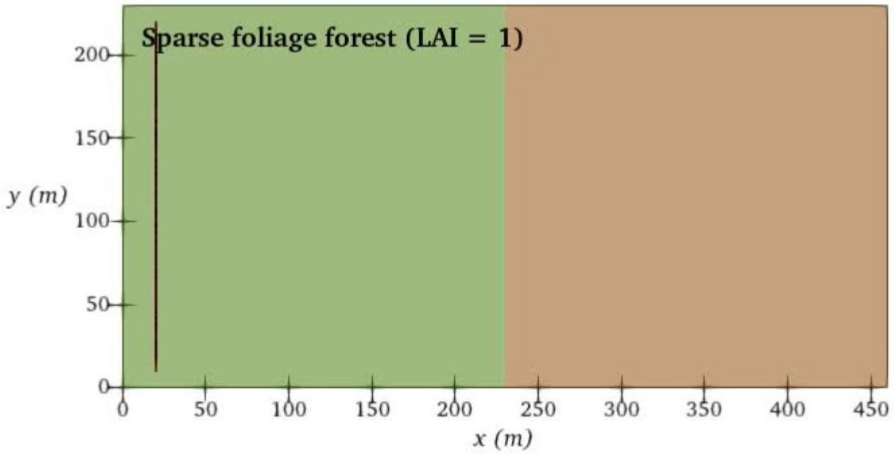
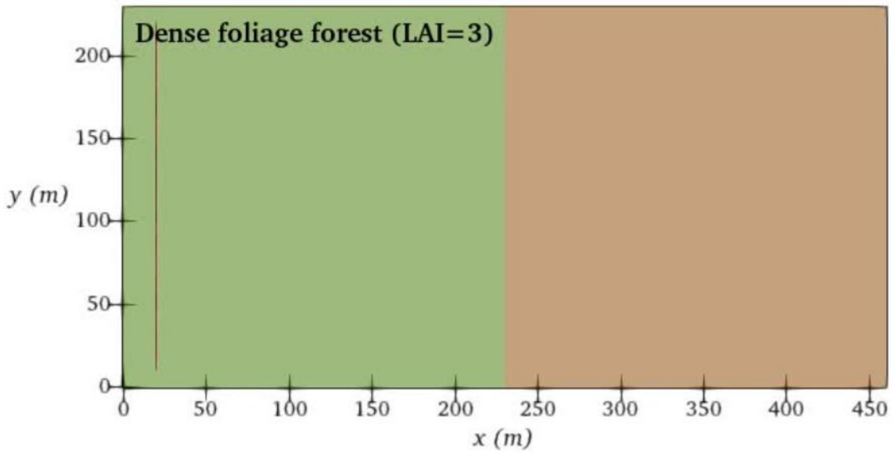
Modelling ember storms at the WUI

Effect of forest density (variable Leaf Area Index)





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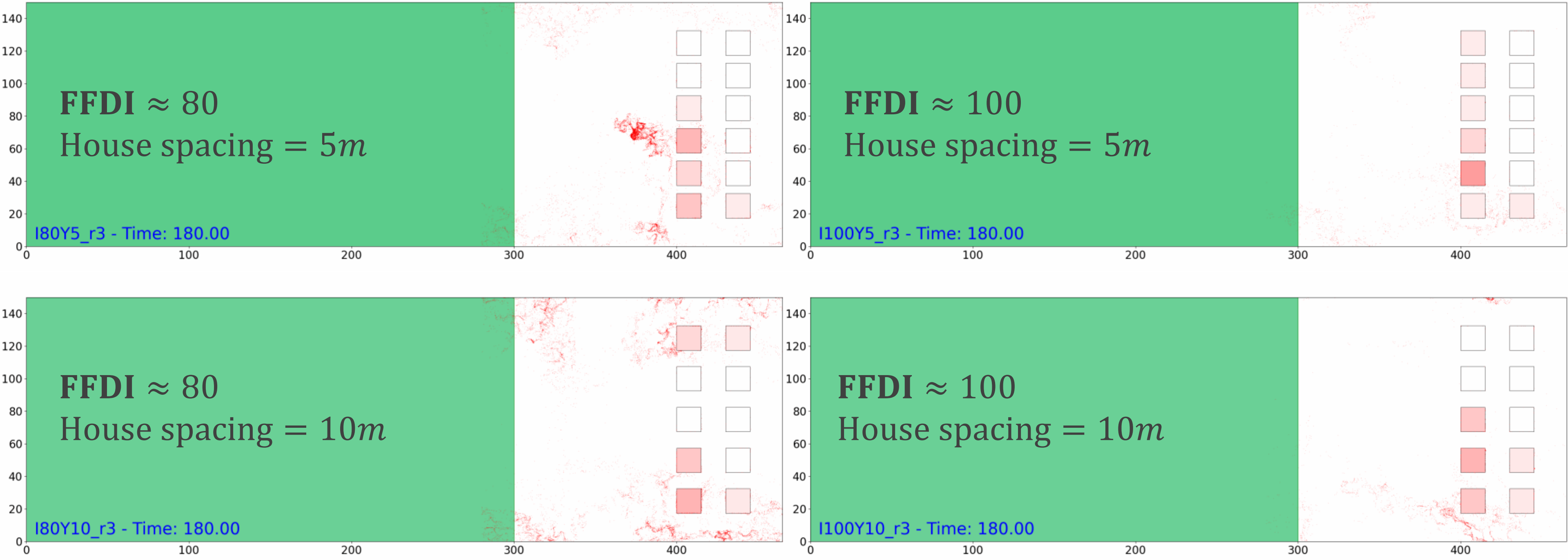
Effect of fire weather & lateral structure spacing…



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Conclusions

- Developed a framework for computational simulation for the lofting and near ground behaviour of embers – an “ember storm” – at the WUI.