ATYPICAL BUSHFIRE SPREAD DRIVEN BY THE INTERACTION OF TERRAIN AND EXTREME FIRE WEATHER

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Introduction

Over the last decade southeastern Australia has experienced a number of catastrophic bushfires that have burnt in rugged terrain under extreme fire weather conditions.

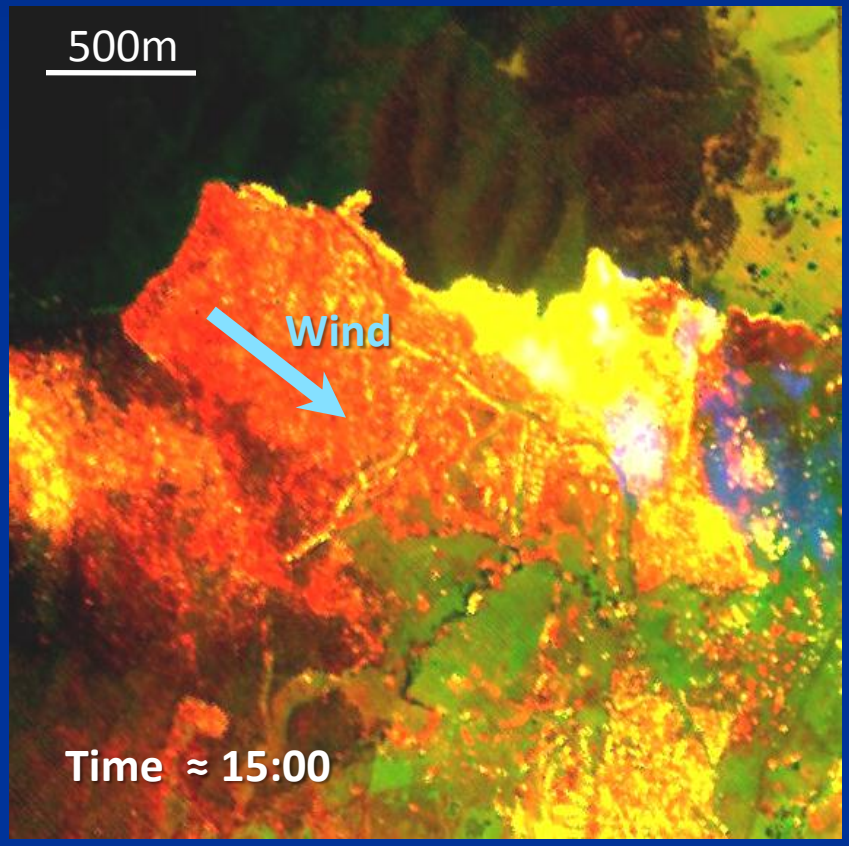
- 2003 Alpine fires (incl. Canberra, 18 January)
- 2006/07 Great Divide Fires
- 2009 Victorian (Black Saturday) fires

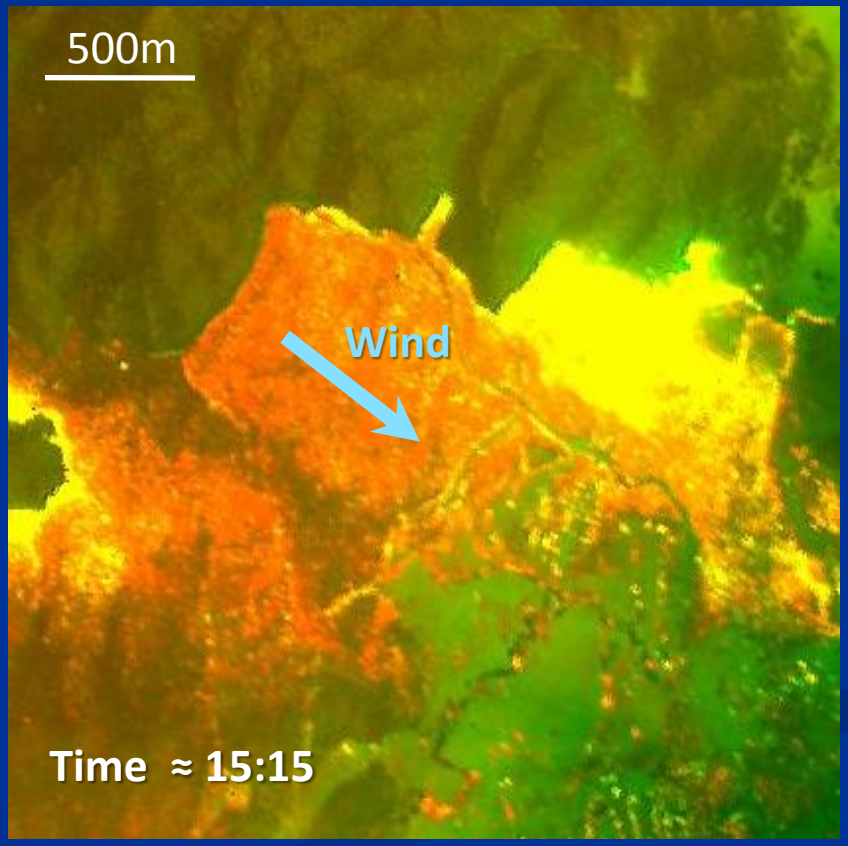
These events are undoubtedly tragic, but they do offer rare opportunities to better understand extreme fire dynamics and associated phenomena.

The 2003 Canberra fires are notable in this respect, with remote sensing platforms, land-based video and aerial photography all capturing various aspects of the fire development

Introduction

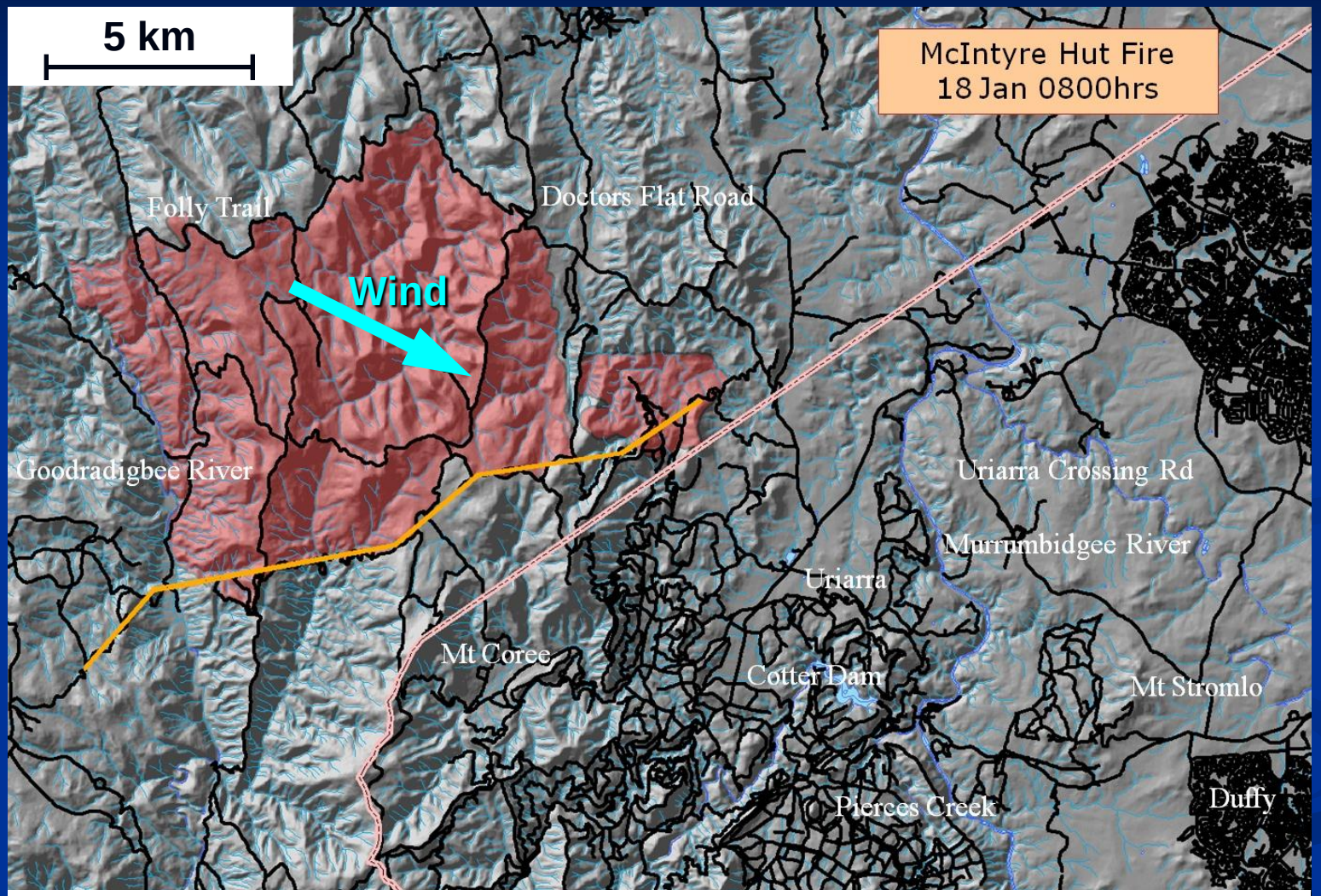
In particular, an airborne mutispectral line-scanning device captured data during the fires' most significant stages of development





Analysis of these data revealed a number of instances of atypical spread

McIntyre's Hut Fire – an example of atypical spread



Powerpoint slides taken from Cheney, N.P. *The January 2003 ACT Fires: Report for ACT Coroner.*

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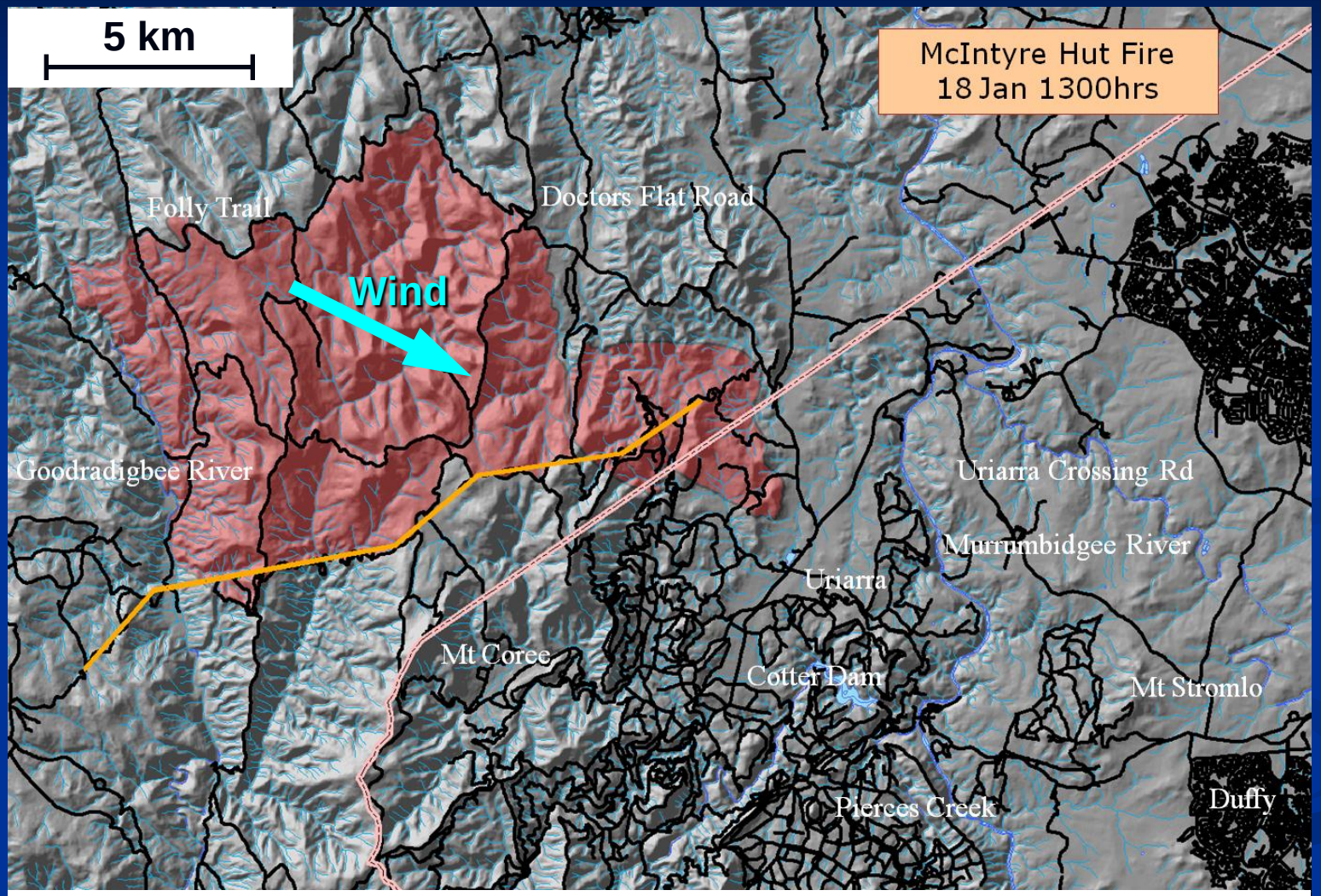

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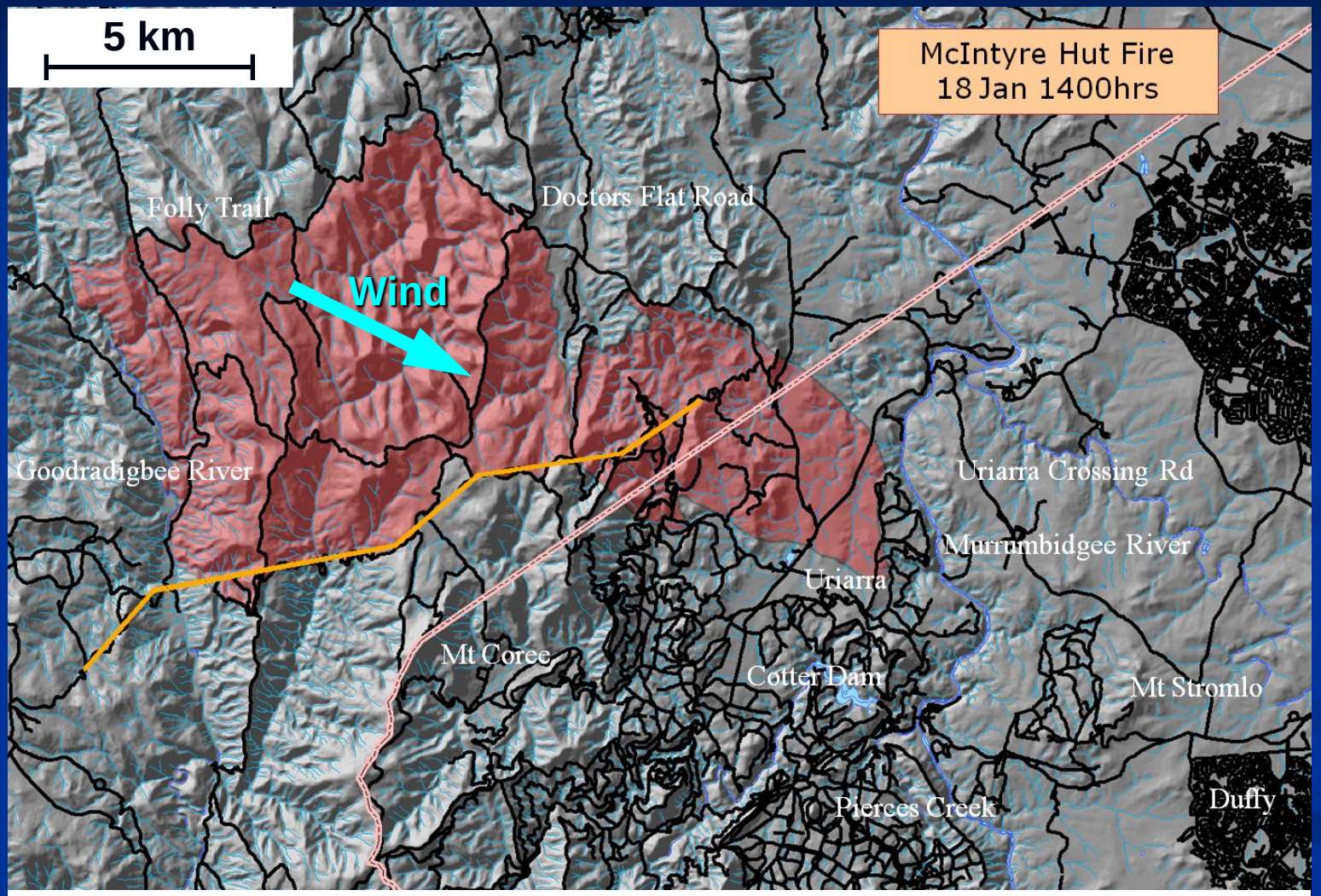

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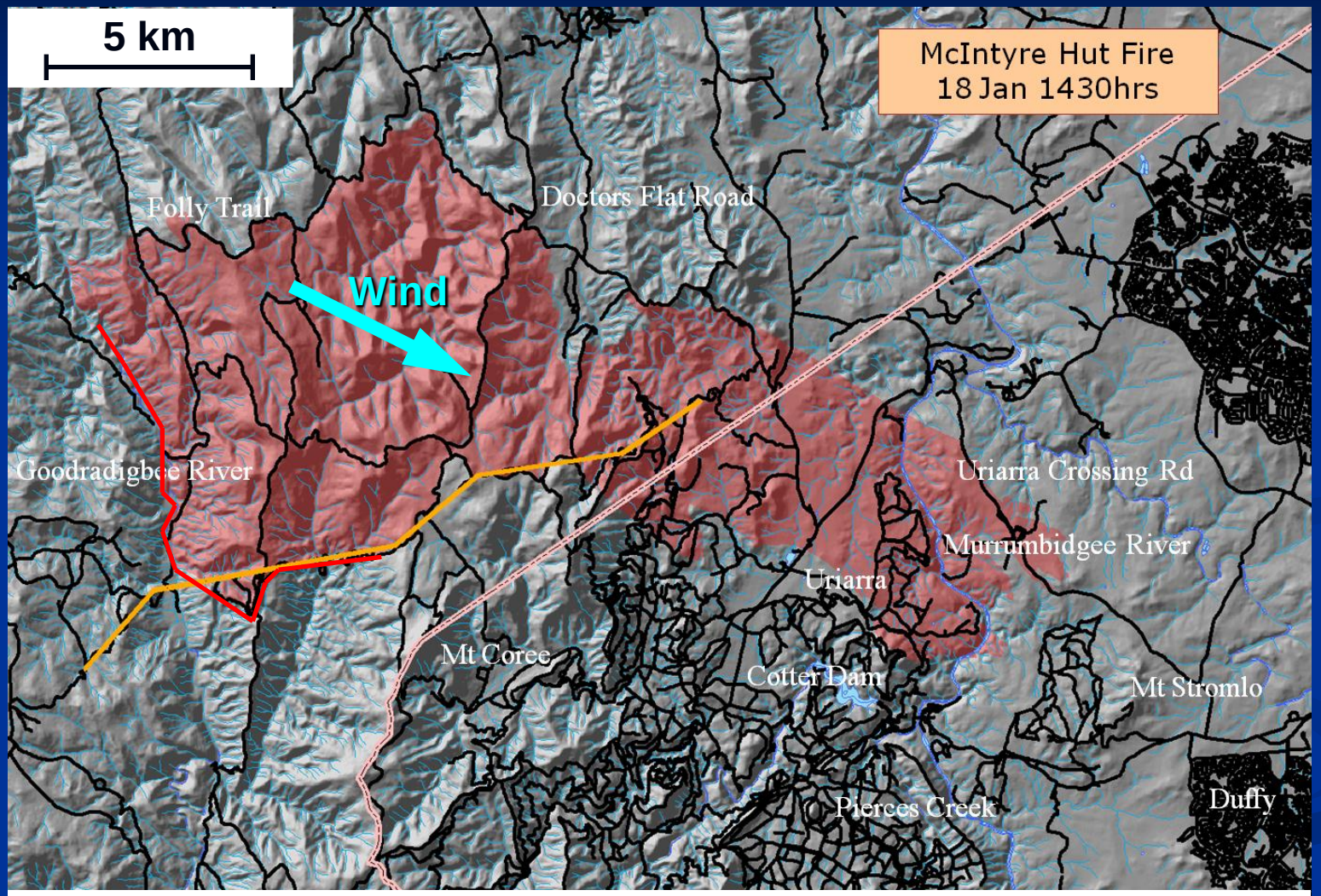

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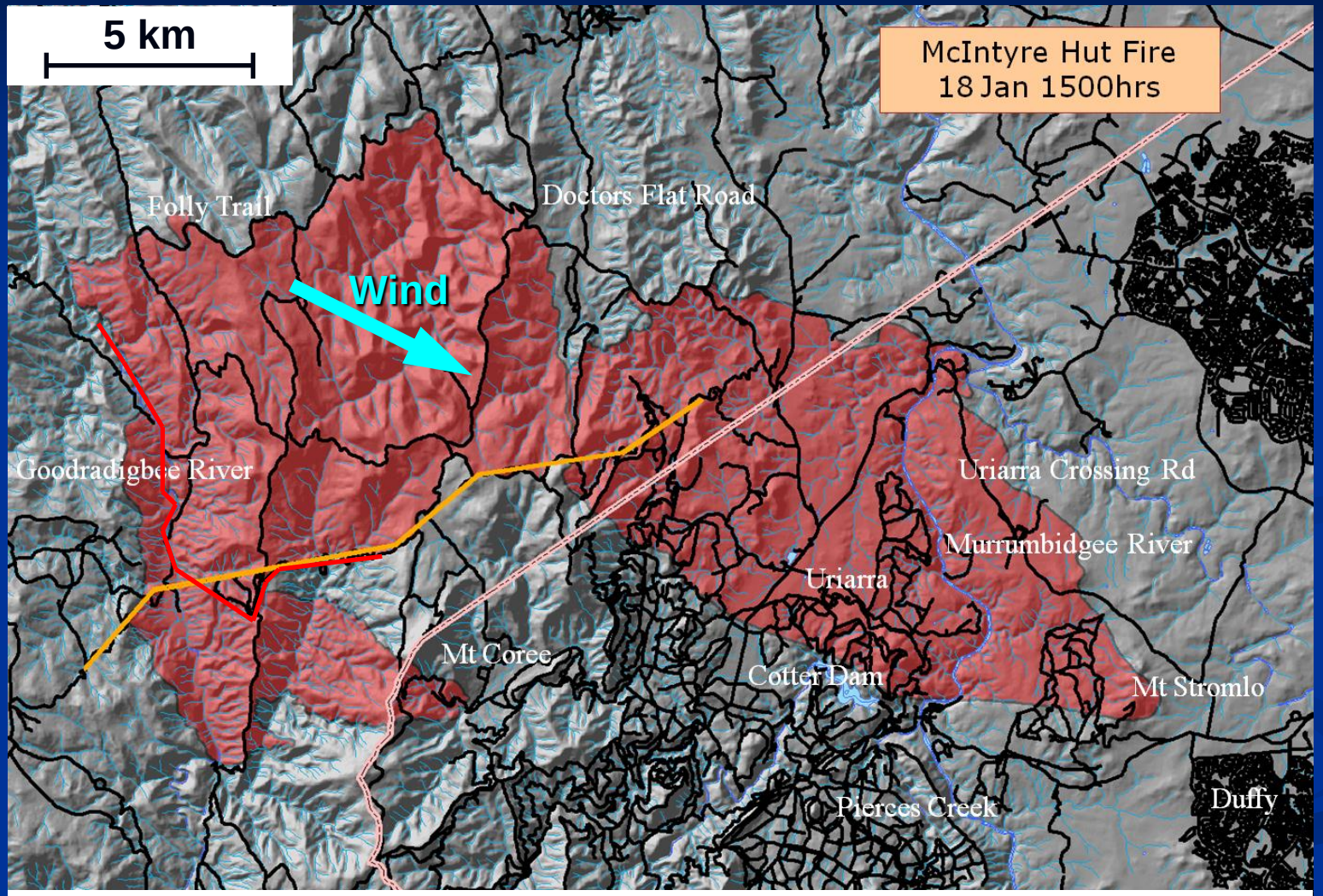

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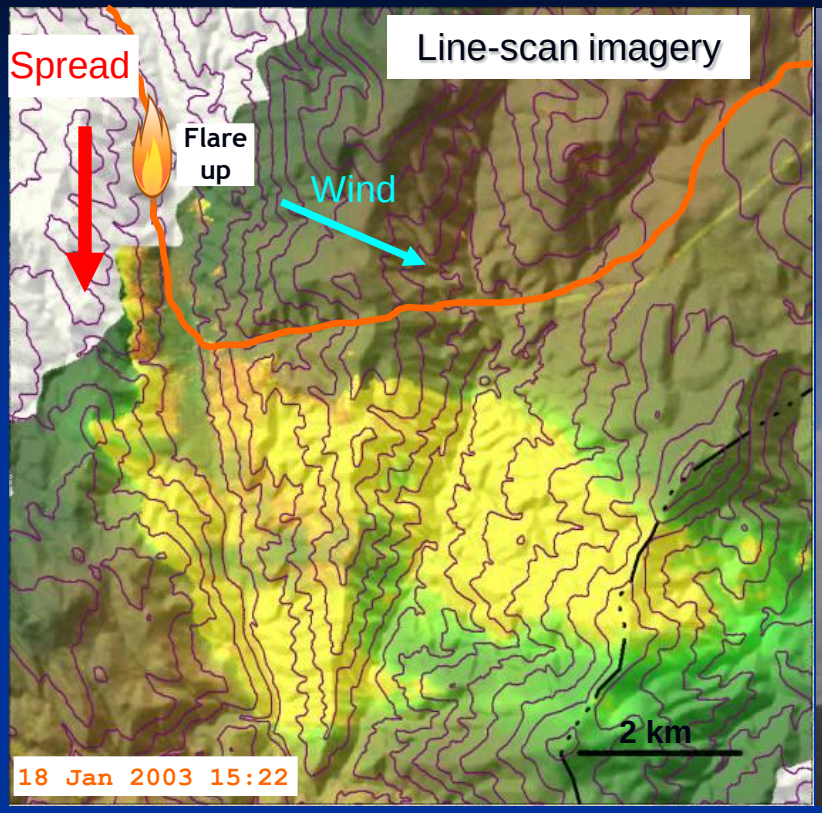


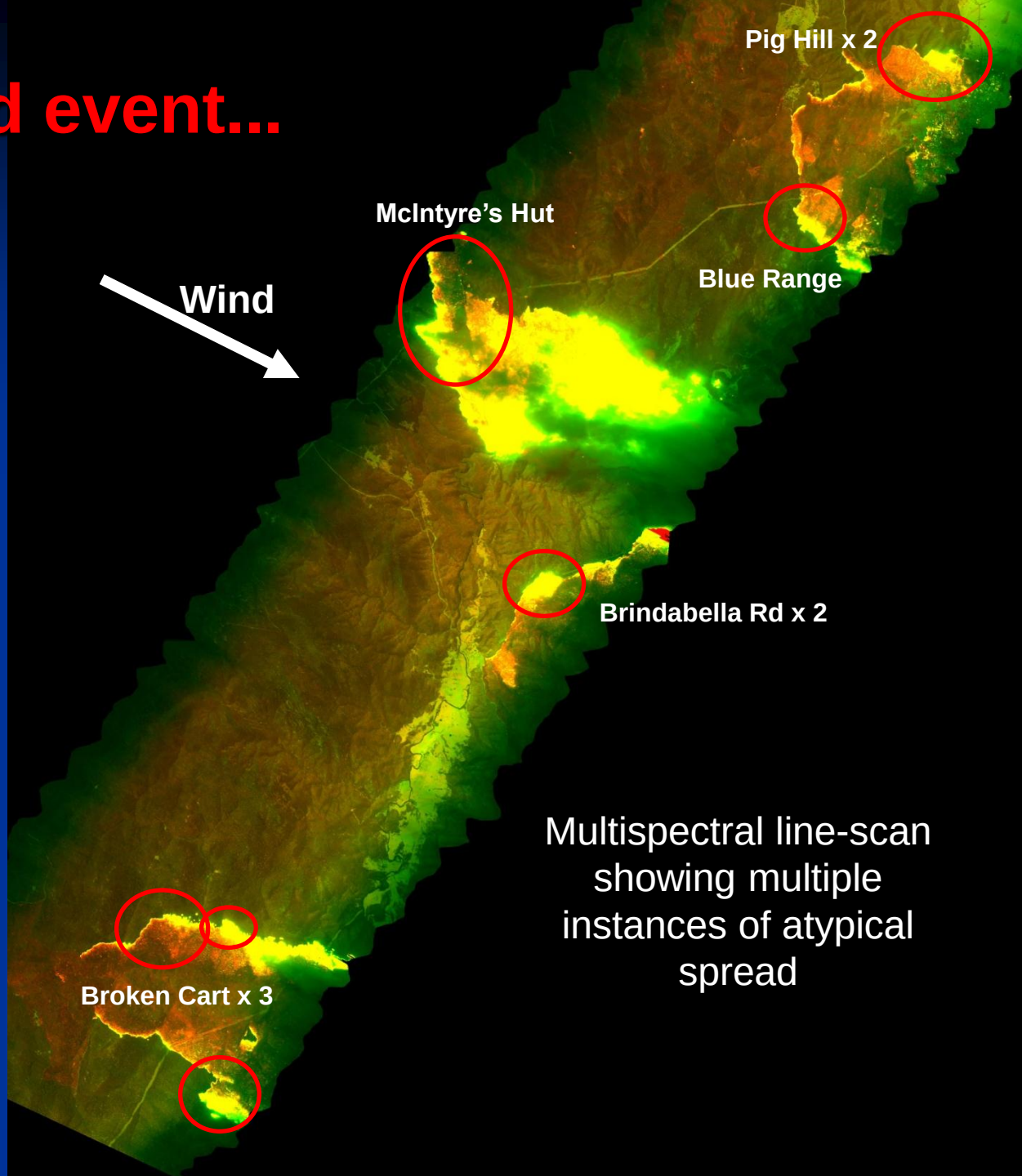
Pyro-Cb over McIntyre's Hut fire 24 minutes after line-scan imagery displays atypical lateral spread

Photo taken around the same time as the line-scan image

Not an isolated event...

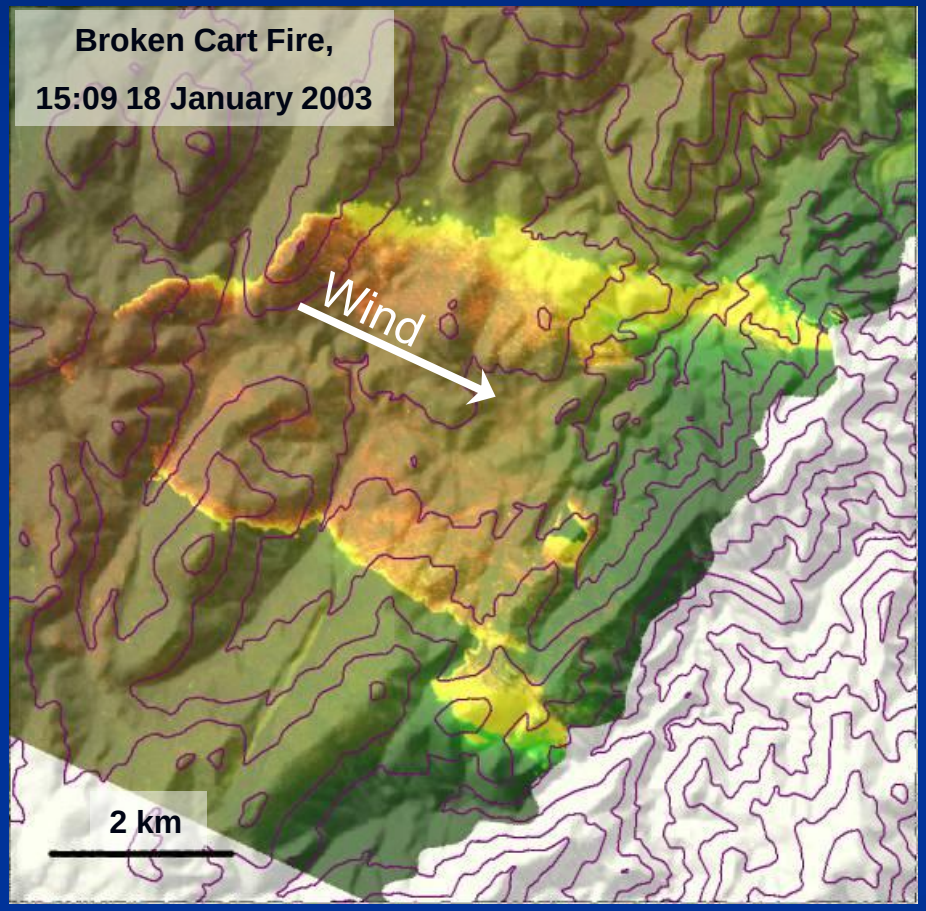
We identified at least 13 similar events on 18 January 2003

Around another 20-25 events have been identified susequently



Multispectral line-scan showing multiple instances of atypical spread

Characterising features of the atypical spread



1. Rapid lateral spread, i.e. across the prevailing winds, as indicated by sharp kinks in the fire perimeter and lateral development of spot fires.
2. Extensive regions of active flame 2 – 5 km downwind.
3. Constrained on the upwind edge by a significant break in topographic slope

We refer to this phenomenon as "fire channelling"

Characterising features of the atypical spread

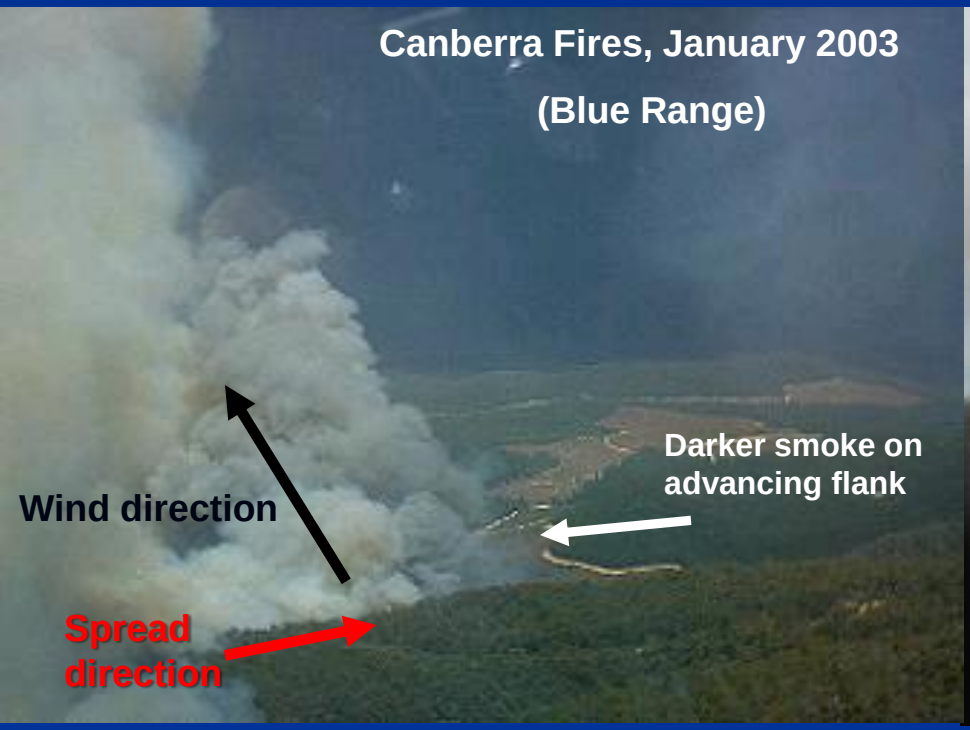


Photo: Stephen Wilkes

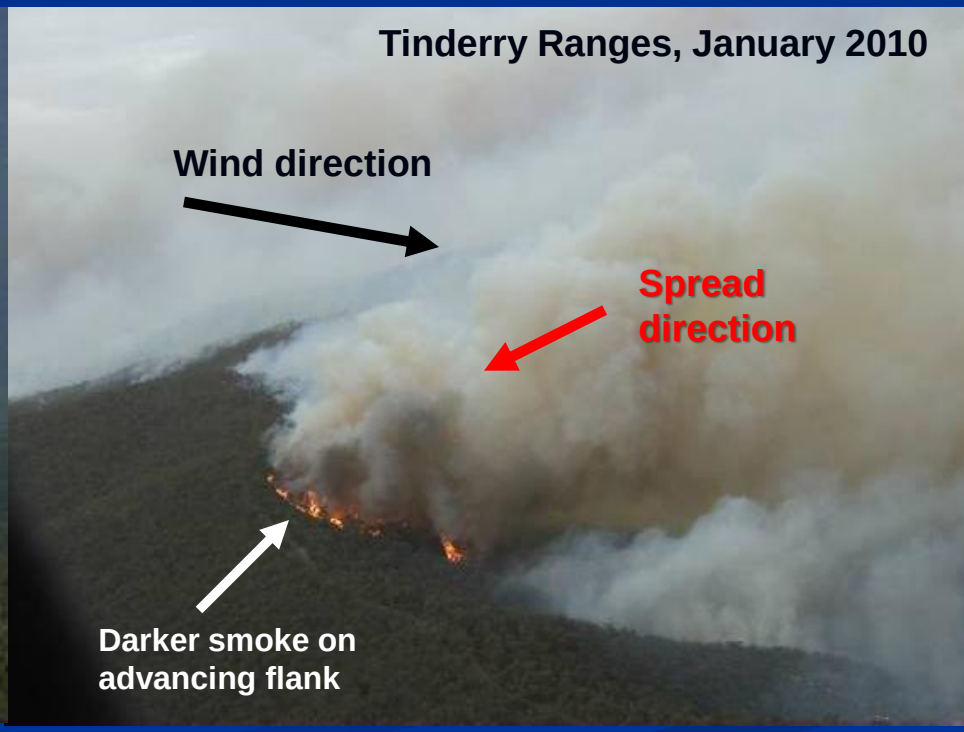


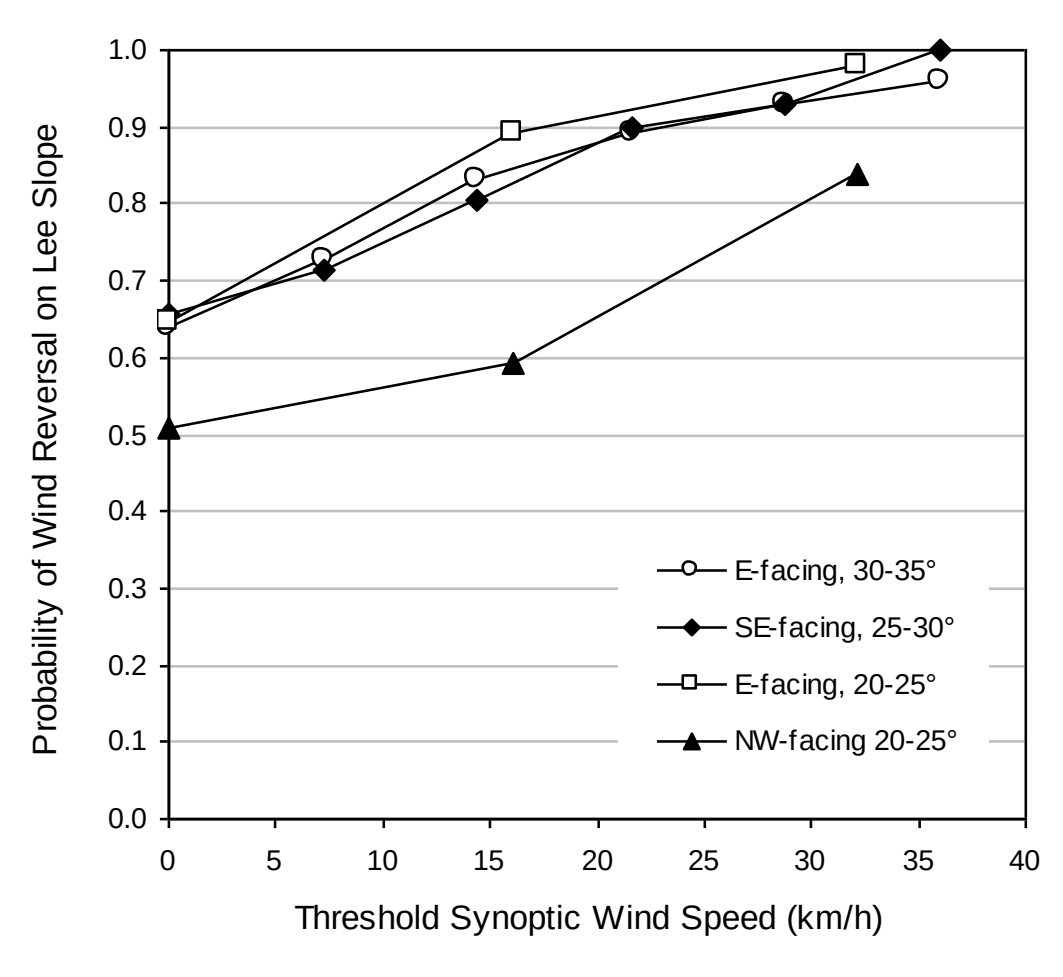
Photo: Steve Forbes

Analysis of wind and terrain conditions associated with fire channelling

Wind: In separate work, as part of the HighFire Risk project, we deployed anemometers in rugged terrain with similar characteristics to that affected by the atypical spread

Terrain: As part of the HighFire Risk work we performed a mathematical analysis of the topographic attributes of the regions affected by the atypical spread

Wind: The effect of wind speed on the probability of a wind reversal on a lee-facing slope



When winds are from the west and are stronger than about 20 km h^{-1}, there is a greater than 90% chance of a wind reversal on easterly aspects with slopes over 20°.

Lee eddies are prevalent!!

Terrain: The role of topographic slope and aspect on fire channelling occurrence

The 'wind-terrain' model

$$\chi(\sigma,\delta)=\begin{cases}1 & \text{if } \gamma_s \geq \sigma \text{ and } \left|\theta_w-\gamma_a\right| \leq \delta, \\ 0 & \text{otherwise.}\end{cases}$$

θ_w is the direction the wind is blowing to

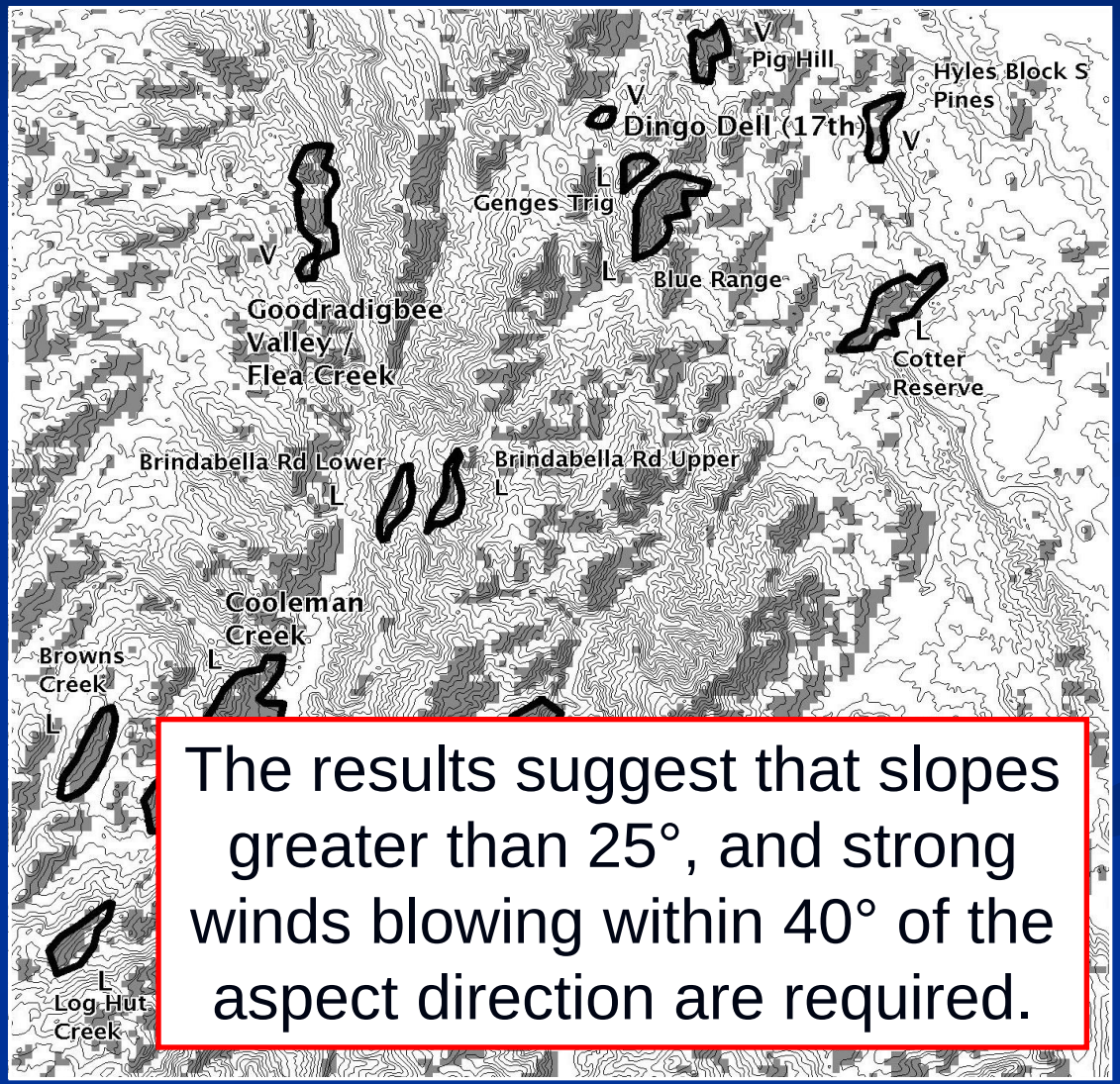
γ_s is the topographic slope angle

γ_a is the topographic aspect

σ and δ are the model parameters

- σ is the threshold topographic slope
- δ is the threshold aspect discrepancy

In simple terms, the model identifies steep slopes that are approx. lee-facing



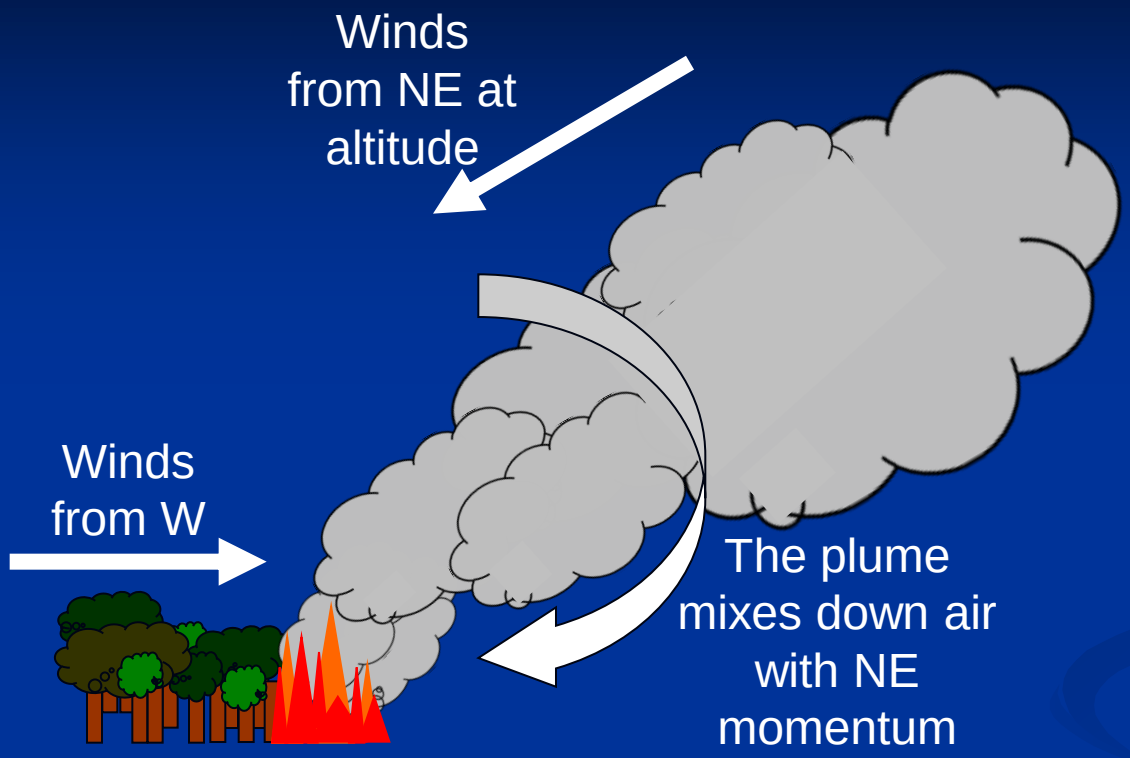
The results suggest that slopes greater than 25°, and strong winds blowing within 40° of the aspect direction are required.

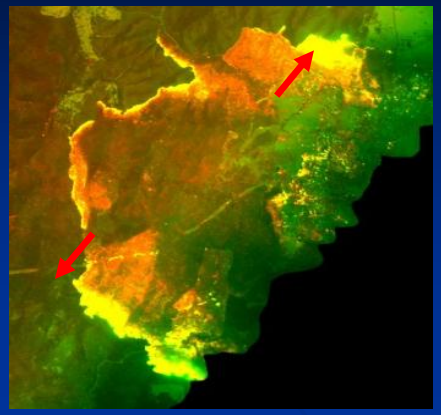
Possible explanations for the atypical spread...

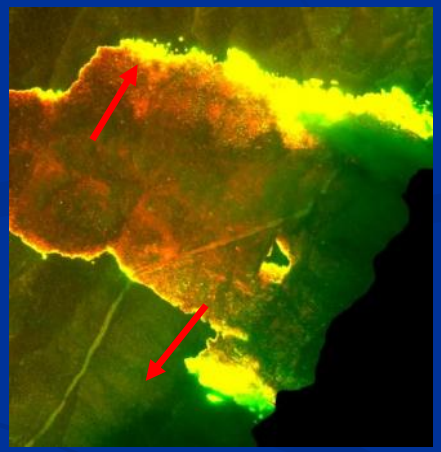
A number of processes might cause a fire to spread laterally:

- Forced channelling
- Pressure-driven channelling
- Downward momentum transport
- ~~Thermal winds~~ → Overpowered by strong winds
- ~~Spatial changes in fuel characteristics~~ → No significant changes in fuel
- ~~In-drafts into other nearby fire plumes~~ → No nearby plumes north of Pig Hill, or south of Broken Cart
- Plume collapse
- Wind-terrain-fire interactions

Downward momentum transport....







However, if downward momentum transport was responsible for the lateral spread, it should all be in the same direction!

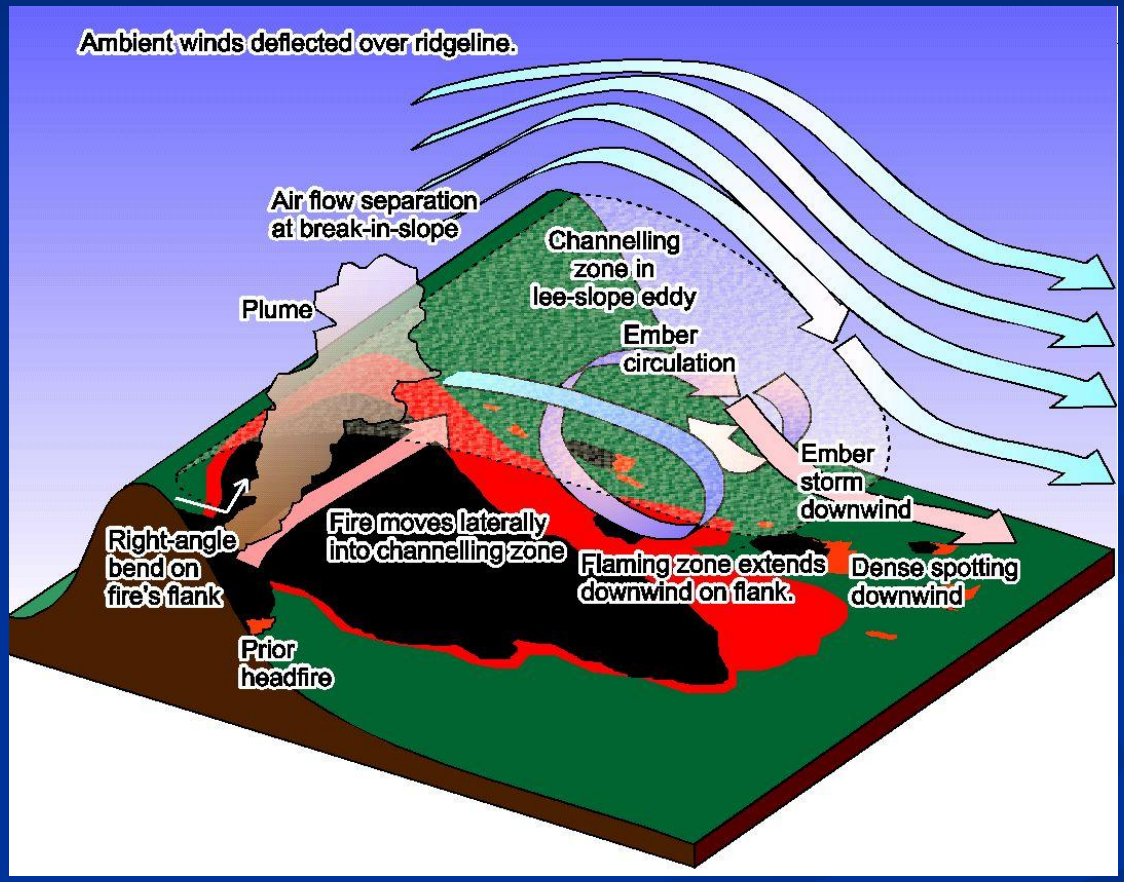
Plus, why should it only affect fires in the lee of steep slopes??

Possible explanations for the atypical spread...

A number of processes might cause a fire to spread laterally:

- ~~Forced channelling~~ → No *prima facie* reason why lee slopes should be identified
- ~~Pressure-driven channelling~~ → Would only cause lateral spread in one direction and effects shouldn't be confined to lee slopes
- ~~Downward momentum transport~~ → Would only cause lateral spread in one direction and effects shouldn't be confined to lee slopes
- ~~Thermal winds~~
- ~~Spatial changes in fuel characteristics~~
- ~~In-drafts into other nearby fire plumes~~
- ~~Plume collapse~~ → No *prima facie* reason why lee slopes should be identified
- Wind-terrain-fire interactions

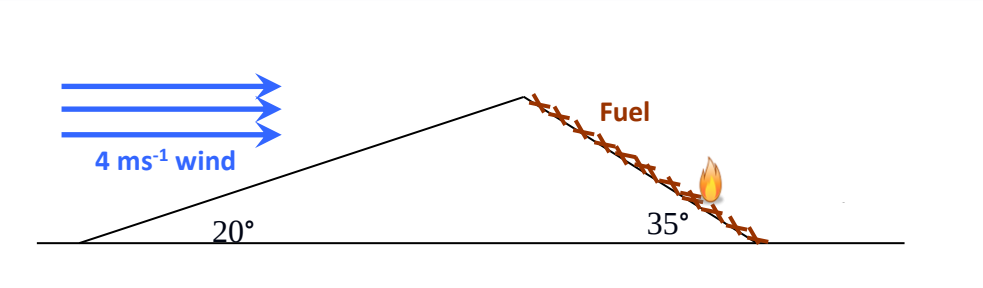
This left us with our best guess at a likely mechanism for the fire channelling phenomenon



Fire channelling hypothesis: ***the fire channelling phenomenon is produced by an interaction between a fire and a lee-rotor***

Combustion Tunnel Experiments

While visiting Prof. D.X. Viegas at the University of Coimbra in August 2010 we sought to further test the fire channelling hypothesis in a series of small-scale combustion tunnel experiments using an idealised triangular ridge geometry.



Schematic view

Actual laboratory set-up

Combustion Tunnel Experiments

Combustion tunnel set-up

Combustion Tunnel Experiments

Results

Right side ignition with no wind

Right side ignition with wind

Left side ignition with wind

Central ignition with wind

COMBUSTION TUNNEL EXPERIMENTS

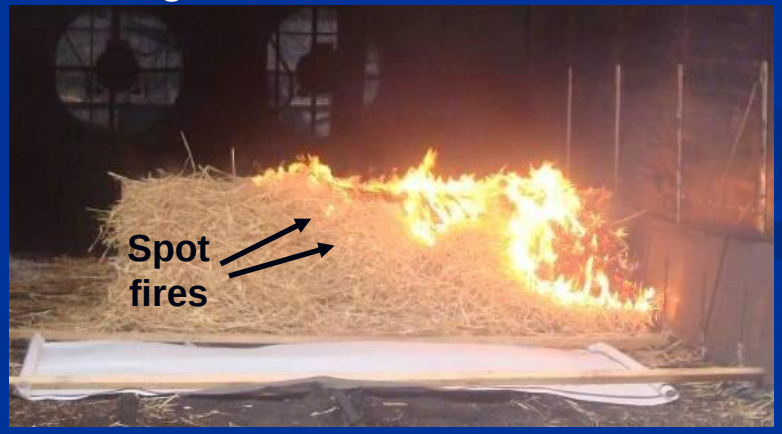
Results

Ignition + 30 seconds

Ignition + 32 seconds

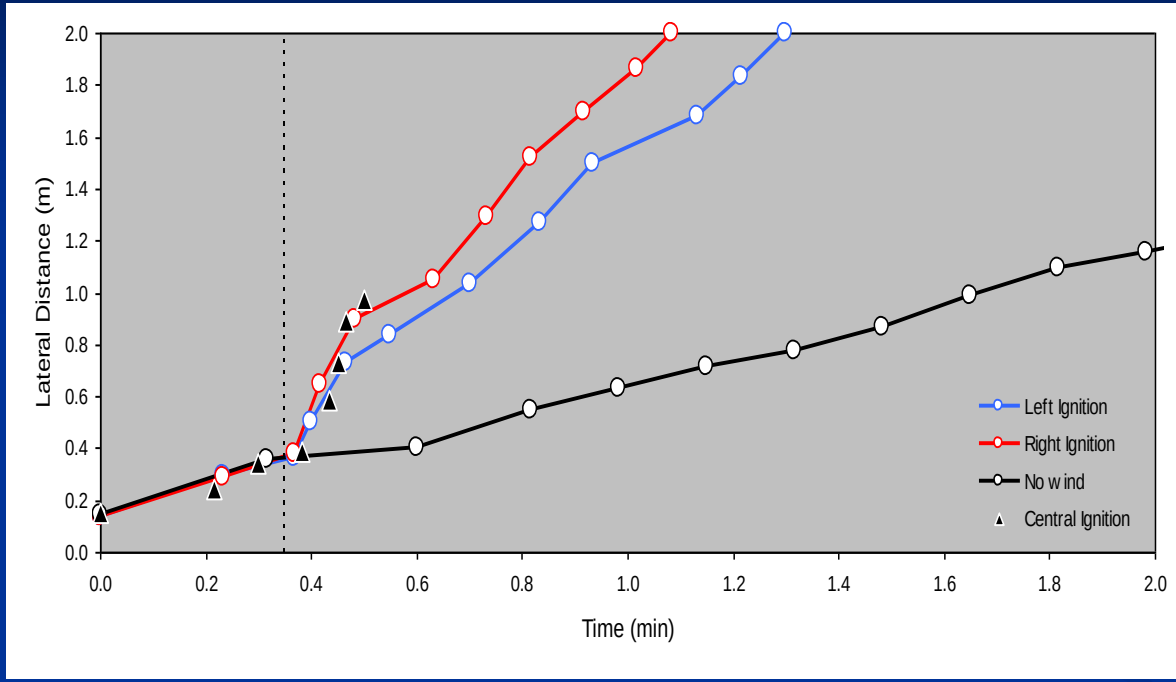
Ignition + 34 seconds

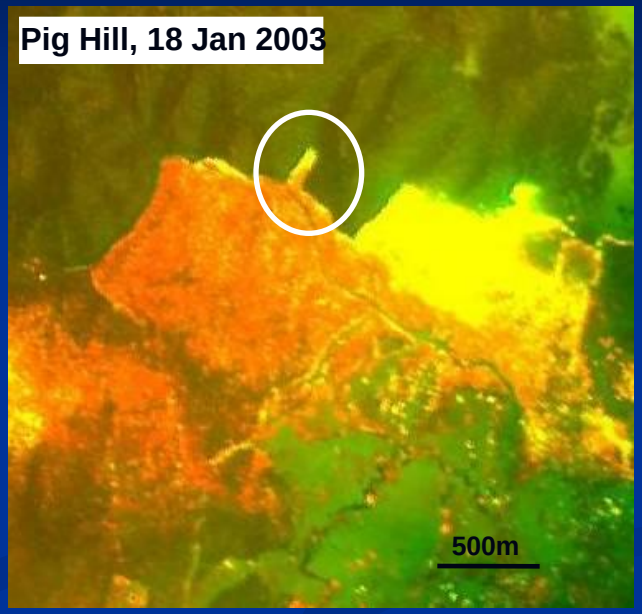
Ignition + 38 seconds



Combustion Tunnel Experiments

Results





The average slopes above indicate that the wind-terrain-fire interaction results in an increase in the lateral rate of spread by a factor of about 4 on average.

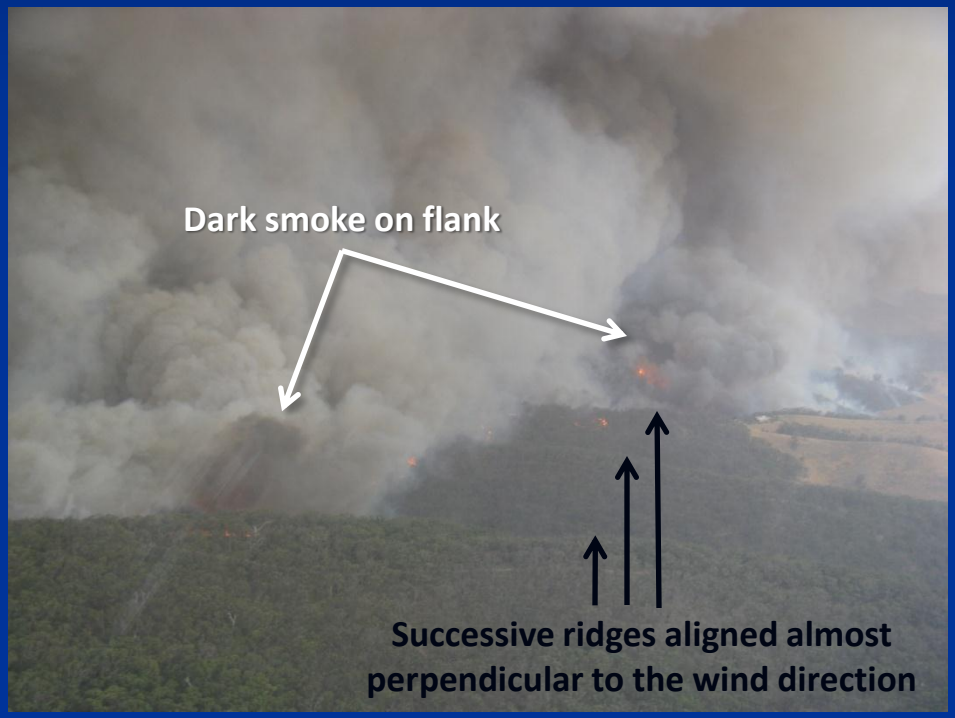
Fire channelling and Black Saturday

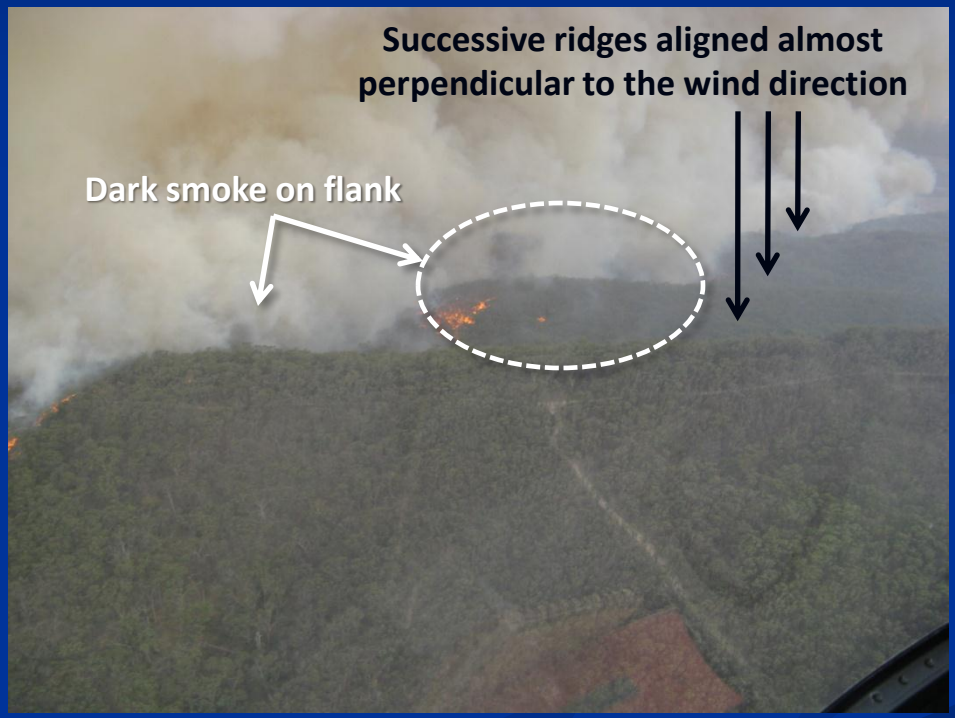
Black Saturday involved rugged terrain and strong winds and so it is natural to wonder about the possible occurrence of fire channelling

While there is only limited evidence available, it does suggest that fire channelling may have played a part in the fire development....

Fire channelling and Black Saturday

Photographic evidence: Kilmore East fire

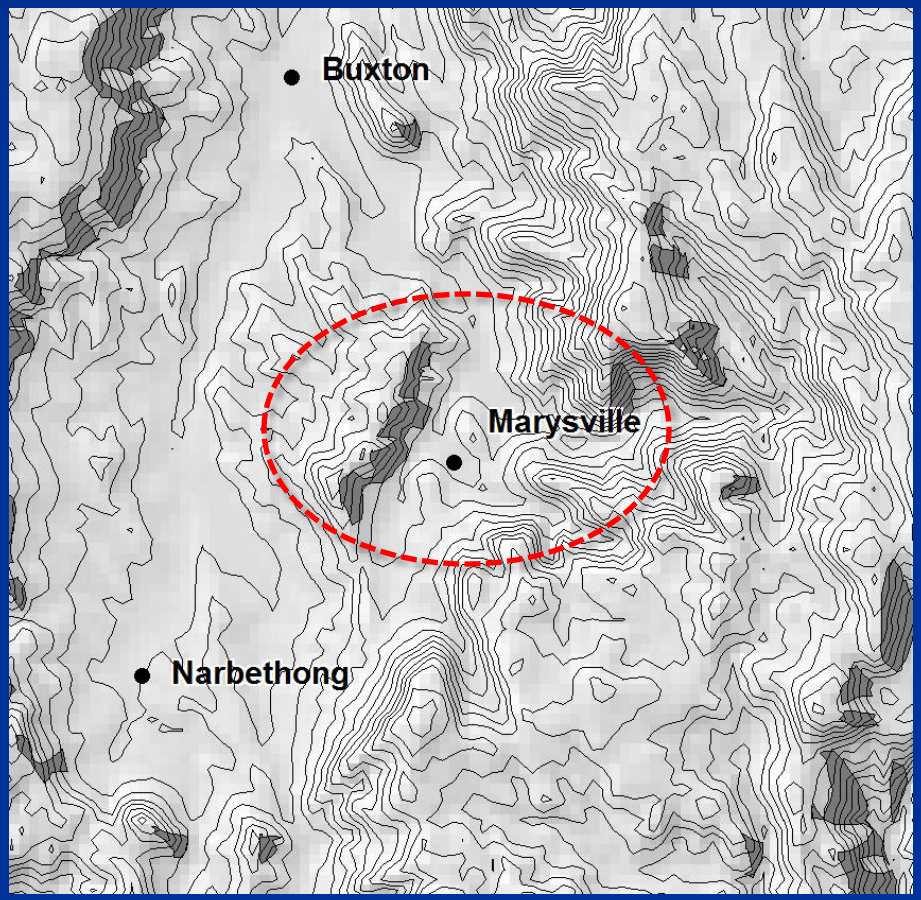




Photos: Richard Alder

Fire channelling and Black Saturday

Marysville – Murrundindi fire



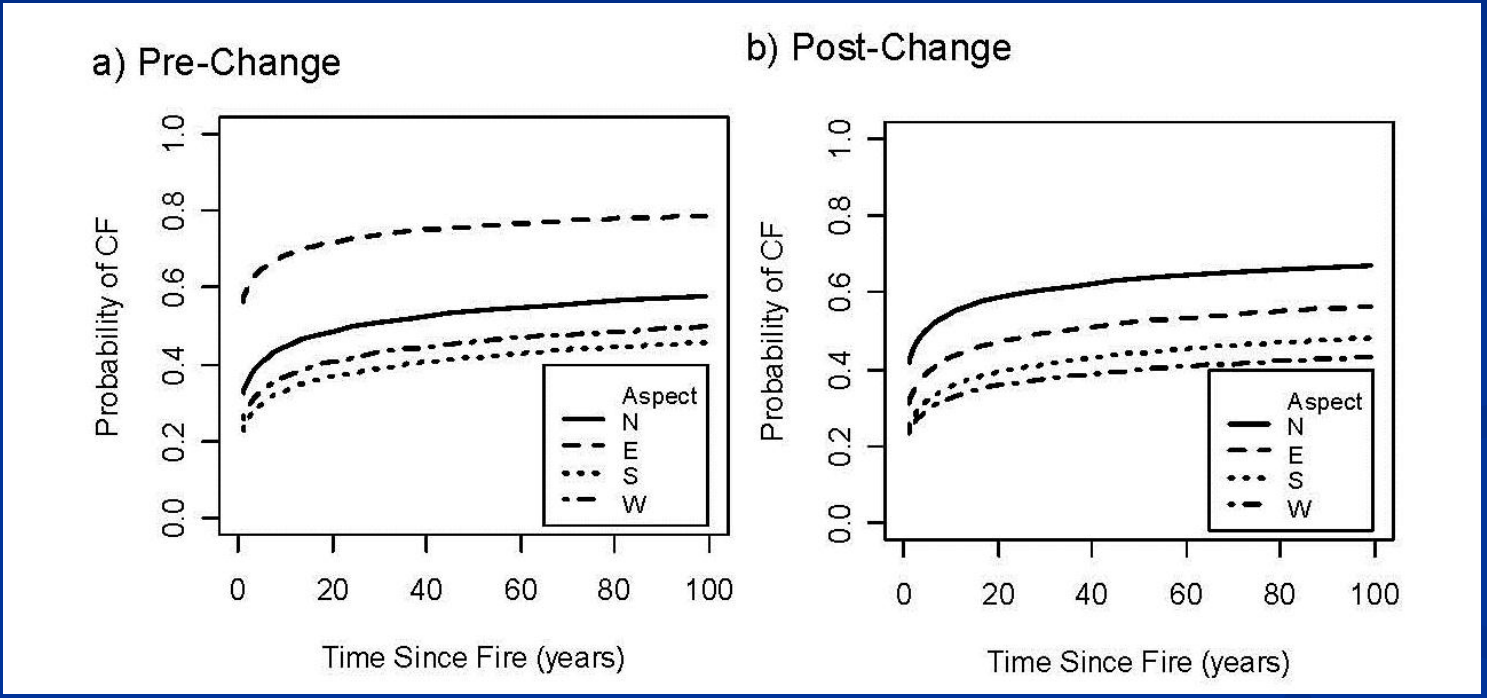
Output of the wind-terrain model for conditions prior to the wind change

The model suggests that the region immediately upwind of Marysville had all the right ingredients for fire channelling

It is possible that the fire was moving north towards the township even before the wind change occurred...!

Fire channelling and Black Saturday

Fire severity patterns



Bradstock and Price found that the highest probability of crown fire was associated with lee-facing aspects...!?!

Future directions:

- Numerical simulation of the phenomena using the Weather Research and Forecasting model

  ⟶ Research Assistant begins in September 2011.

- More experiments with Prof. Viegas' team (different wind speeds, slope angles and orientation of the ridge)

  ⟶ work already underway:

  H.A.S. Farinha (2011) *Formation of Vortices in a Forest Fire - Laboratory Study of a Vortex of Horizontal Axis and a Tornado of Fire.* M.Sc Thesis, University of Coimbra.

- Quantitative study of fire severity patterns from Black Saturday

- Investigation into possible fire channelling events in Blue Mountains, New Zealand, Sardinia, Portugal, etc.

Acknowledgements

- ACT Rural Fire Service
- Australian Academy of Science
- A/Prof. Rod Weber, UNSW Canberra
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- Len Carter, NSW Rural Fire Service
- Kasy Cambers, ACT Rural Fire Service (Gungahlin RAFT)
- Air Target Services Pty. Ltd.
- NSW Rural Fire Service
- Bushfire CRC
- School of PEMS Mechanical and Electrical Workshops