



Fire Development, Transitions and Suppression

Peter Ellis, Miguel Cruz, Jim Gould, Matt Plucinski and Andrew Sullivan

CSIRO Ecosystem Sciences and CSIRO Climate Adaptation Flagship

End User Leader: Simon Heemstra

NSW Rural Fire Service

What is the potential for fires to break out?

What is the historical fire occurrence for given fire weather?

What is the probability that an ignition source will succeed to a self-sustaining fire?

How fast is a fire going to develop under given weather?

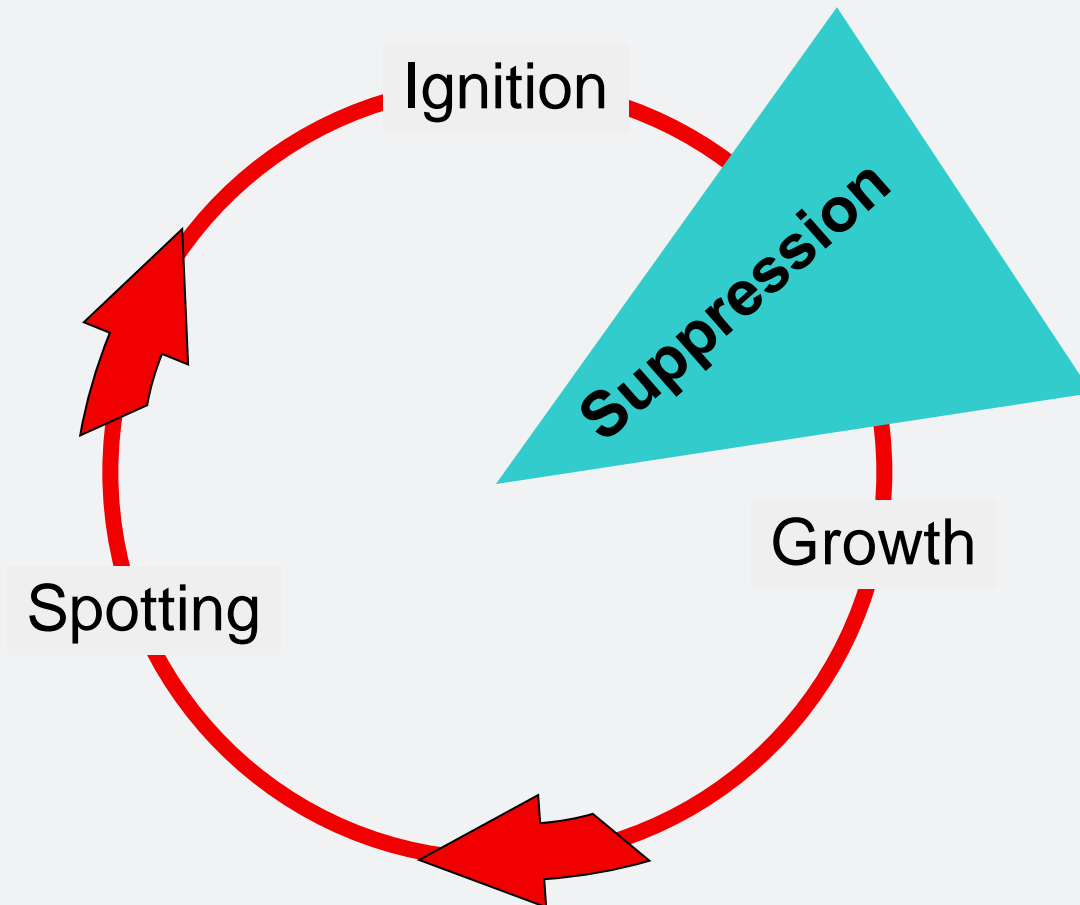
When will that fire start to throw spotfires?

How quickly will those spotfires develop and begin spotting?

How long will initial attack be possible? (i.e. How long before the fire will surpass initial attack efforts?)

How much suppression resource will be needed to put out any given fire?

How much suppression resource will be needed for any given day/period/season?



Three interlinked research components:

A. Firebrand potential and spotfire/ignition initiation

- Peter Ellis
- *will extend firebrand flight and combustion knowledge to other notorious species, develops an understanding of the transport and ignition potential of firebrands under a range of fuel and weather conditions*

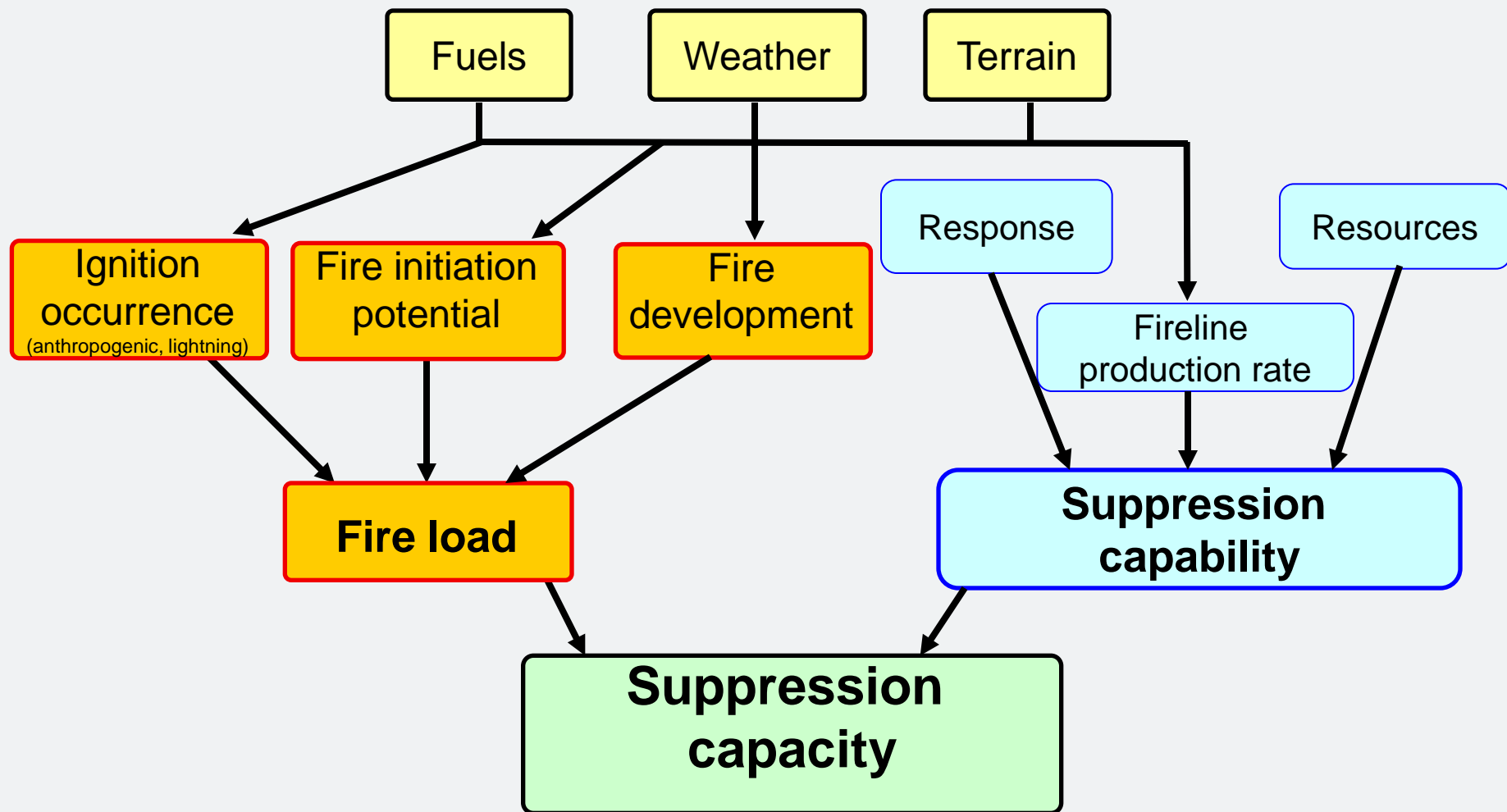
B. Fire development and transitions

- Jim Gould (development), Miguel Cruz (transitions)
- *will develop understanding of the rate of growth of fires from point ignitions under a limited range of fuel and weather conditions*

C. Fire load and suppression resourcing

- Matt Plucinski
- *will develop fire occurrence model that with ignition initiation and fire development will form fire load model. Will develop framework and underpinning understanding for a suppression resource allocation tool.*

Resource allocation optimisation components

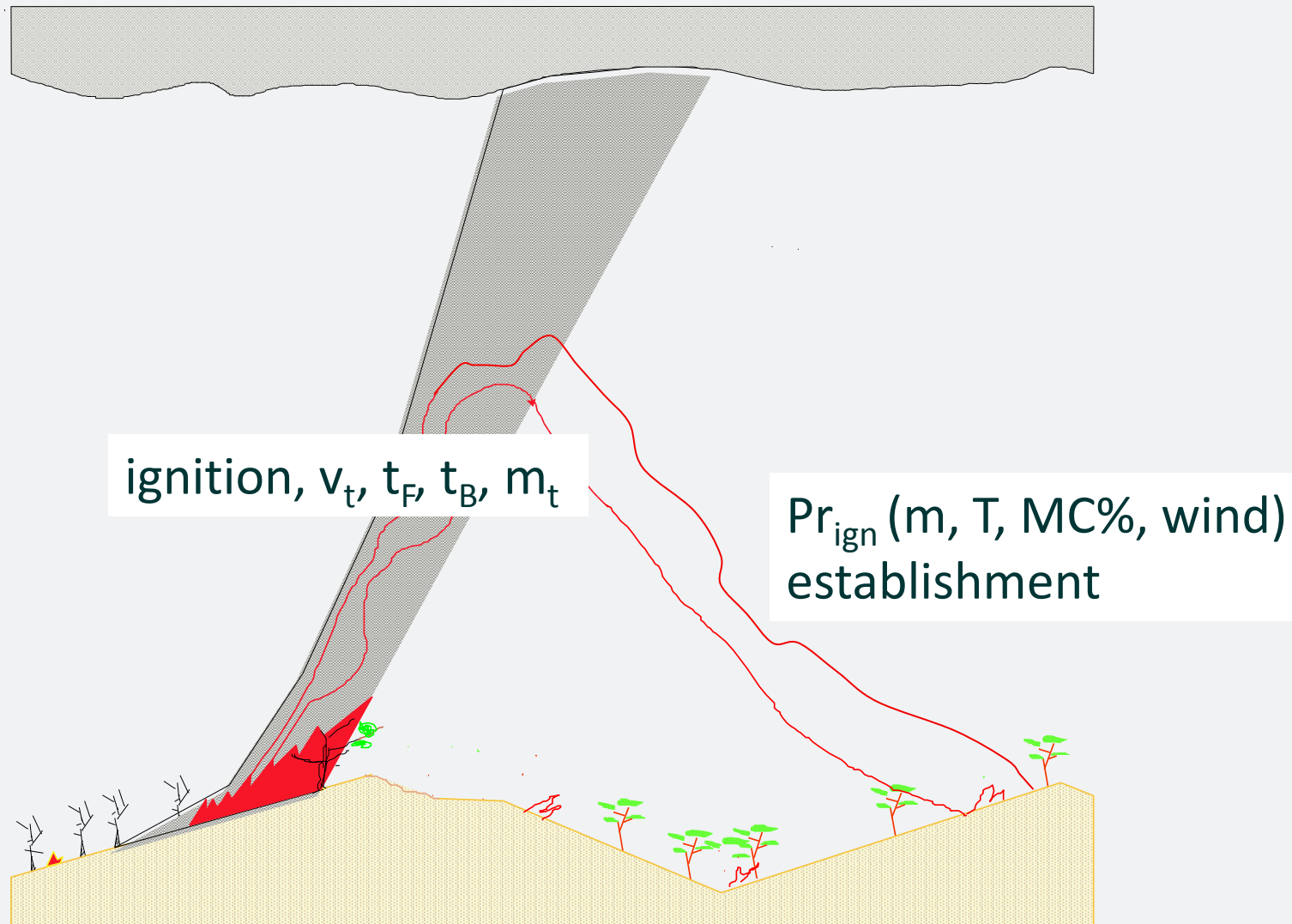


Will enable fire agencies to better plan for fire incidents, periods and seasons across multiple spatial scales

1. 3-year scope, independent, non-sequential, non-contiguous for the most part.
2. Primarily laboratory-based (CSIRO Vertical Wind Tunnel and CSIRO Pyrotron)
3. Possible field-based experimentation
4. Need for field validation and verification (access dependent)
5. Incorporates two student research areas:
 - Resource productivity and response
 - 2-year MSc study (UWoll in NSW, others?)
 - Agency-based individuals
 - Firebrand flight and combustion characteristics
 - 3-year PhD study (institution to be determined)
 - Yet to engage students.

SPOTTING DURING EXTREME FIRE WEATHER

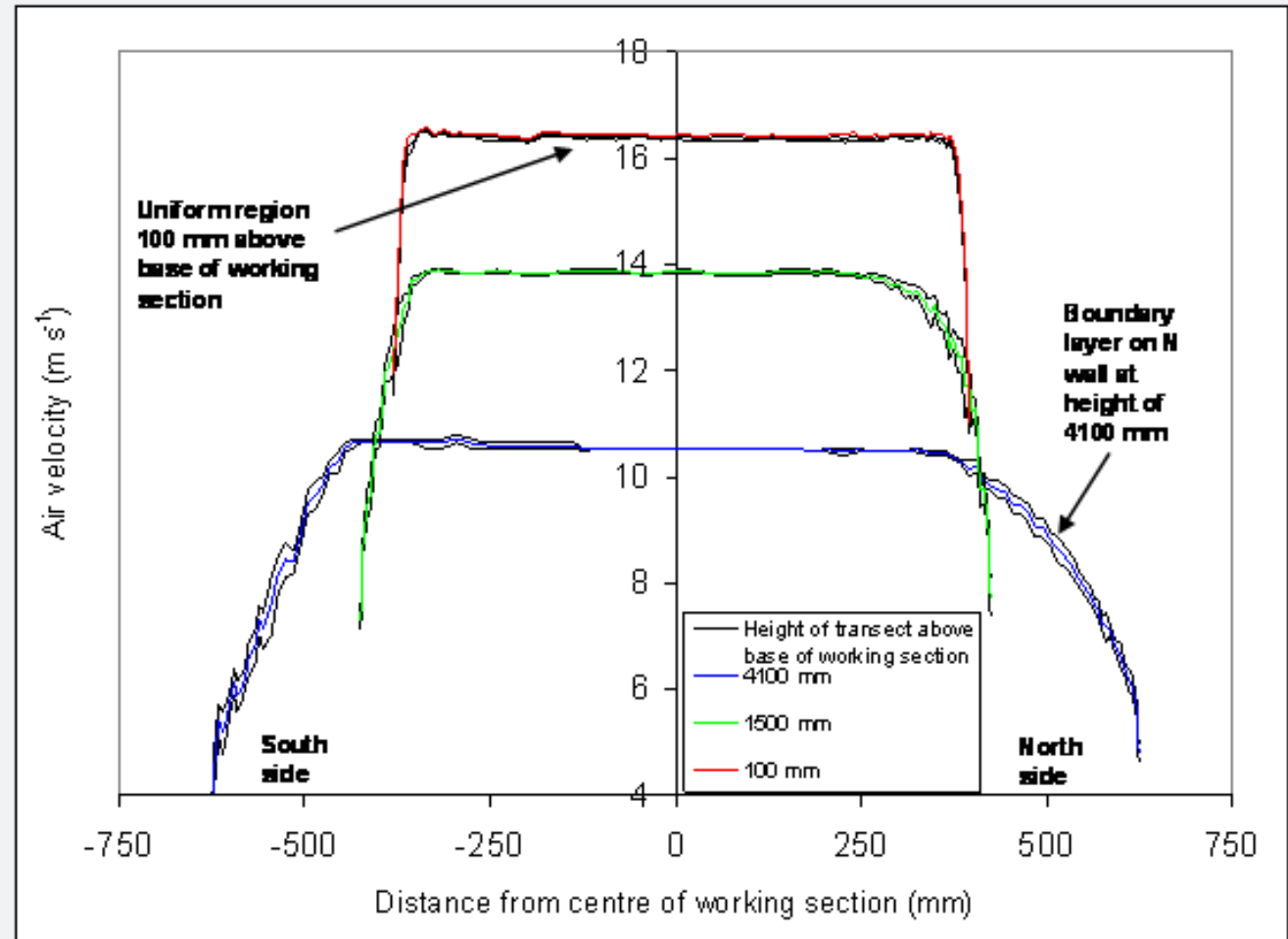
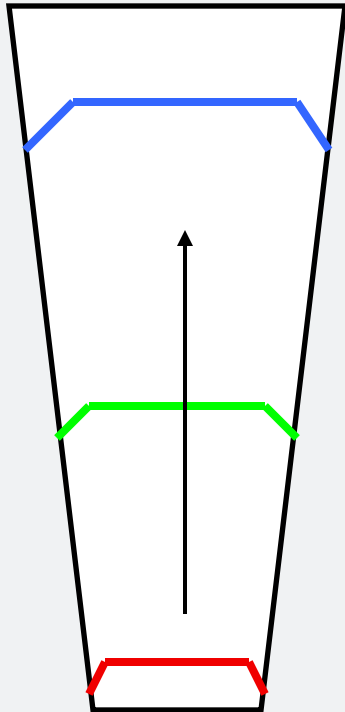
(Peter Ellis)



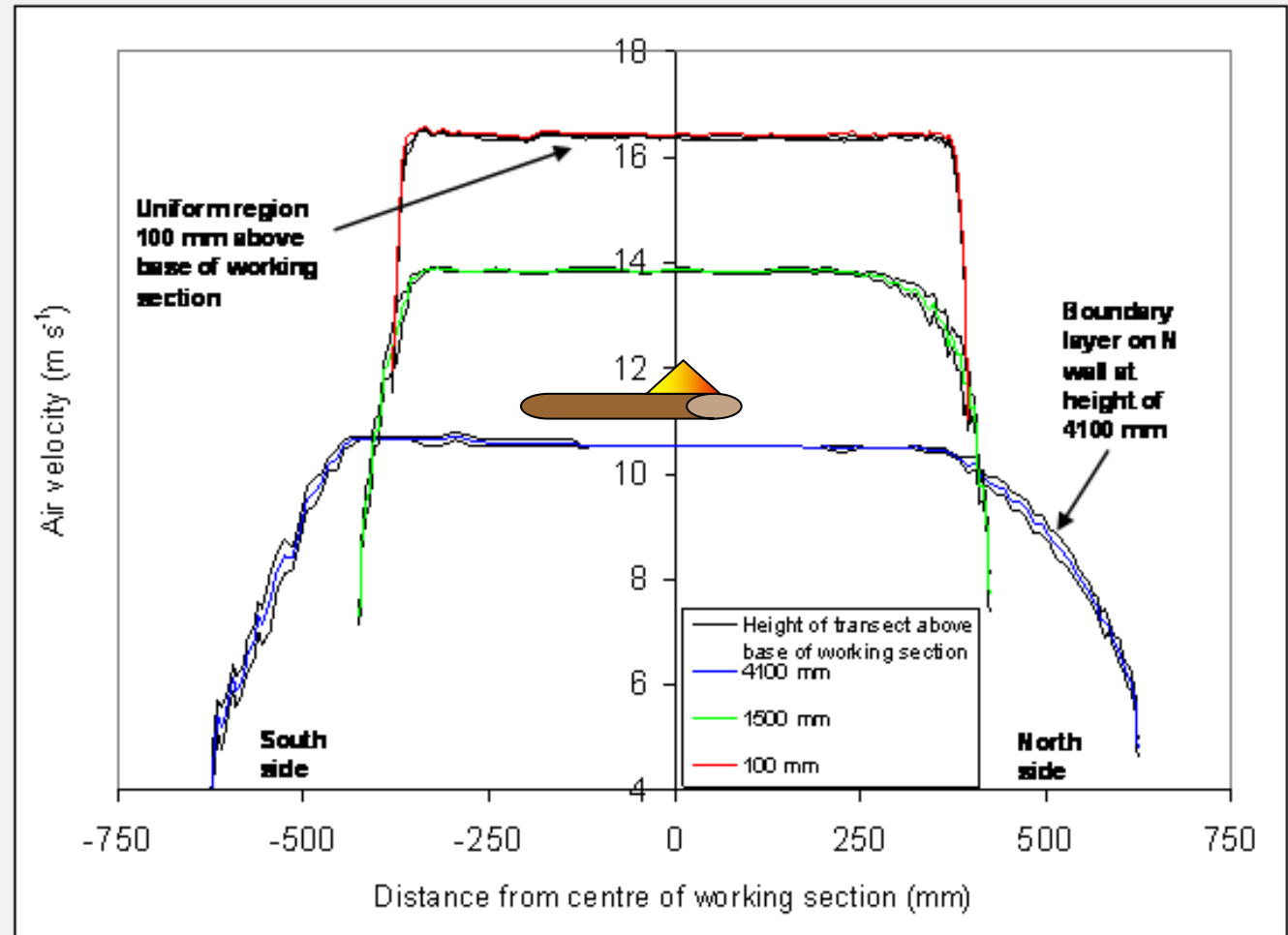
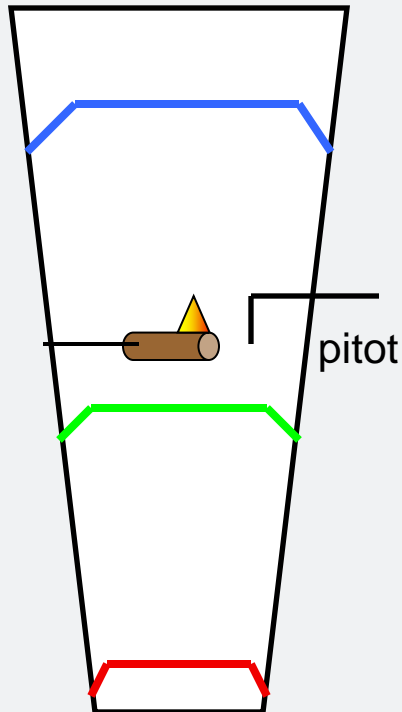
1. Velocity profile of CSIRO Vertical Wind Tunnel (report)
2. Fuelbed ignition by firebrands (review)
3. Firebrand aerodynamics and combustion (review)
4. Black Saturday (East Kilmore) spotting (report)

Potential research directions

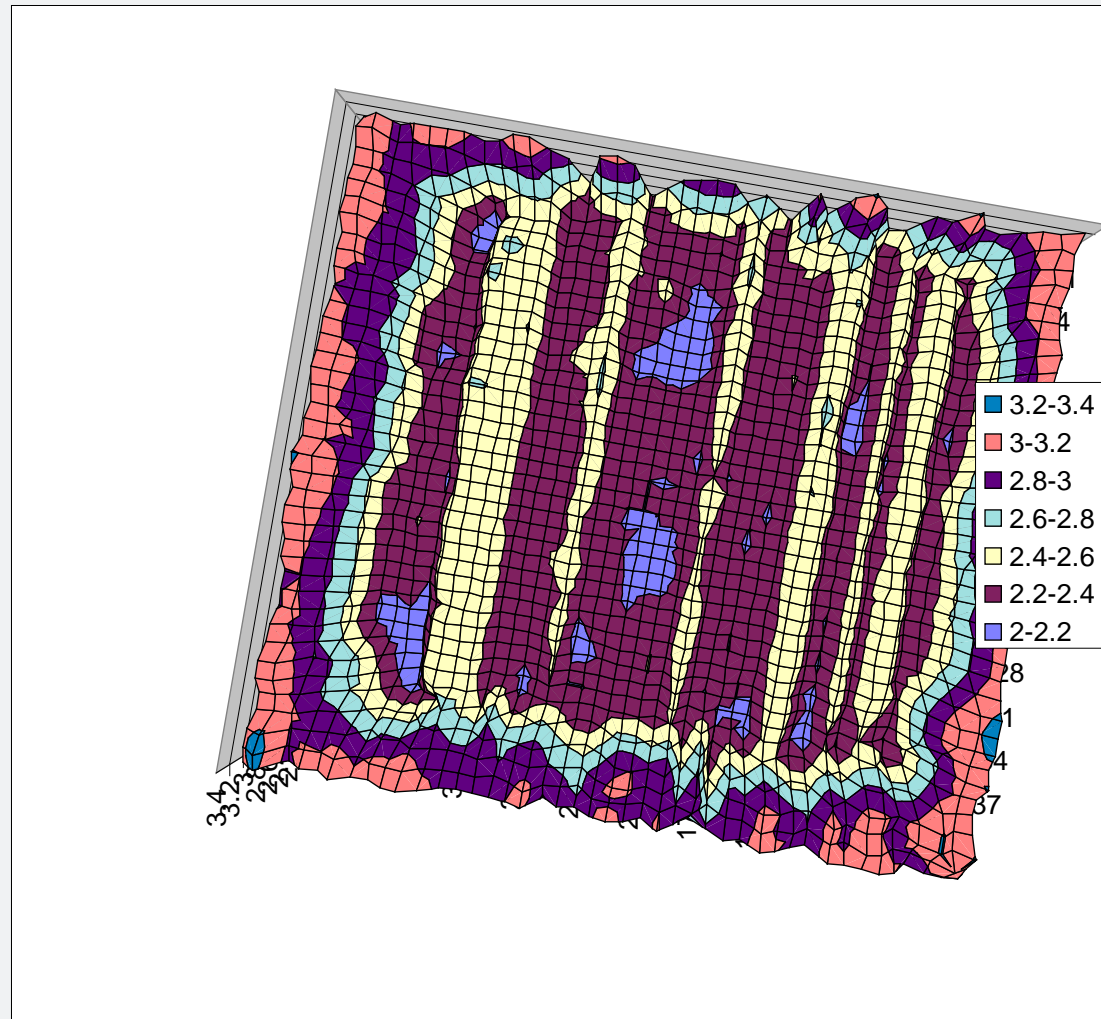
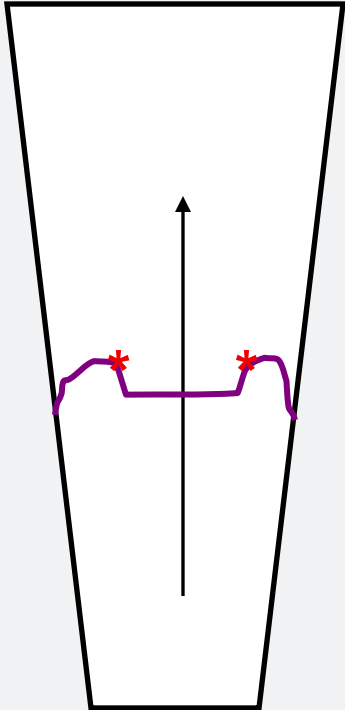
1. Velocity profile of vertical wind tunnel - A



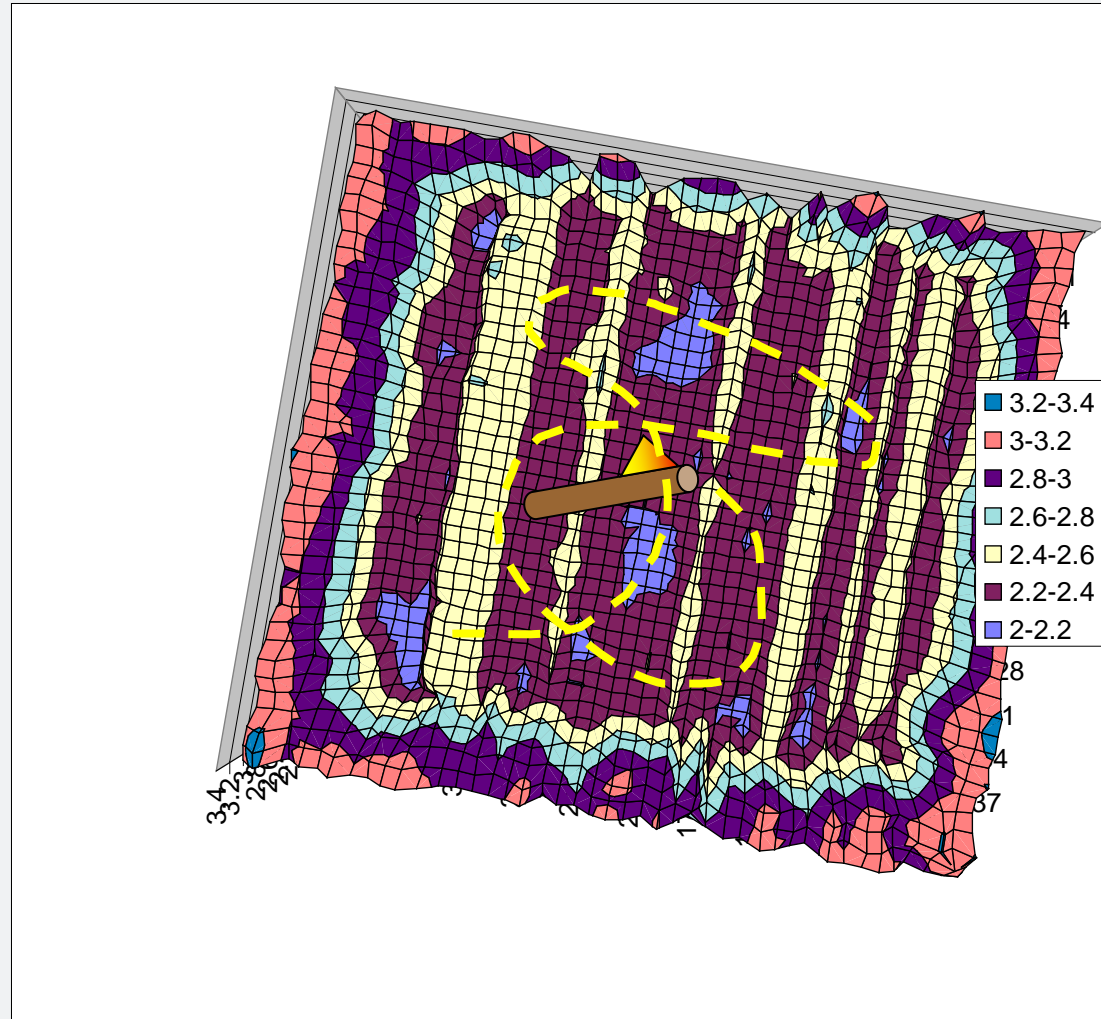
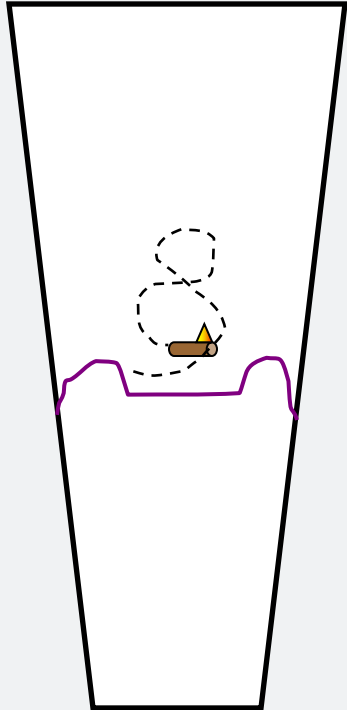
1. Velocity profile of vertical wind tunnel - A



1. Velocity profile of vertical wind tunnel - B



1. Velocity profile of vertical wind tunnel - B

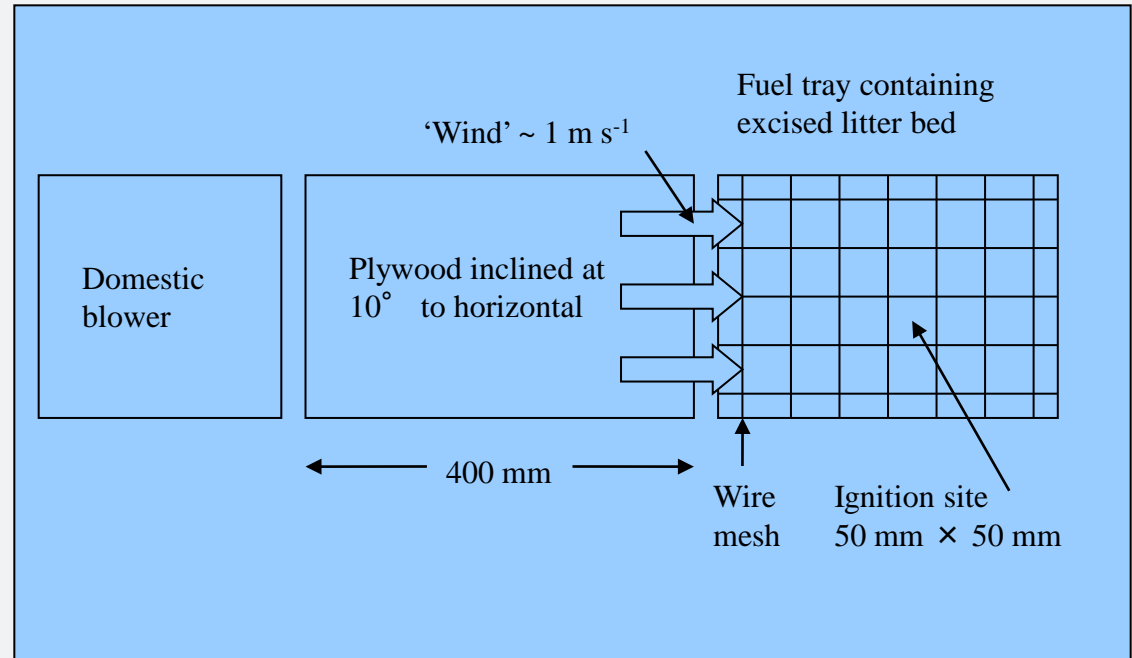


2. Fuelbed ignition by firebrands (review)

Knowledge for eucalypts

1. Experimental techniques
2. Messmate the best
3. Blue gum good
4. Wind for glowing firebrands
5. Wind orientation
6. Firebrand mass, fuel bed MC
7. ~ 0.1 g firebrand successful

(Ganteaume *et al.* 2009, Ellis 2011)



2. Fuelbed ignition by firebrands

New stuff/challenges

1. Little info out there for eucalypts (messmate, globulus)
2. Validate knowledge
3. Leaves/grass vs needles
4. Fuel bed heterogeneity
5. Tiny firebrands can spot
6. New facility, + field experiments?

3. Fb aerodynamics and combustion (review)



Knowledge for eucalypts:

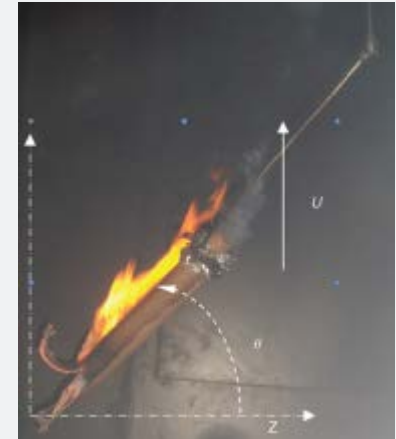
1. Empirical experimental techniques/facility
2. Messmate = fair
3. Jarrah = some
4. Karri = little
5. Ribbon/candle = little
6. (Ellis 2000, Ellis 2010, Ellis in press, Ellis in prep.)

3. Fb aerodynamics and combustion

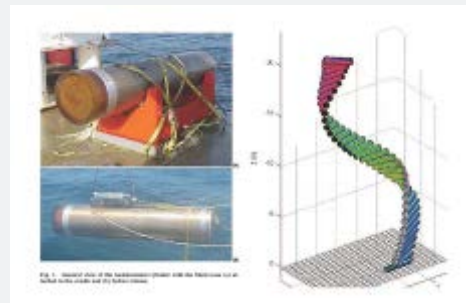
(Ellis 2000)

New stuff/challenge

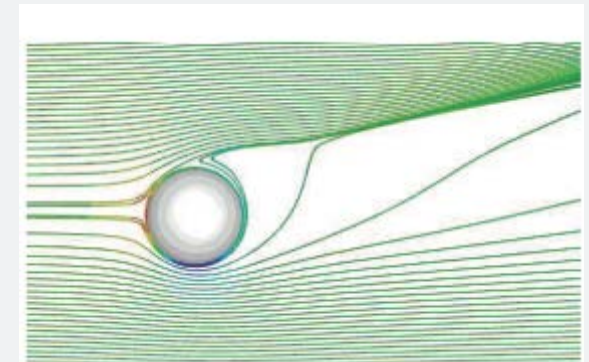
1. Very little out there
2. Burning at one end, little
3. Falling cylinders' new
4. Above, burning, new
5. Potential for use of CFD, physical
6. No PhD student yet



(Almeida *et al.* in press)



(Abelev *et al.* 2007, oceanic engineering)



(Ou *et al.* 2011, app. aerodynamics)

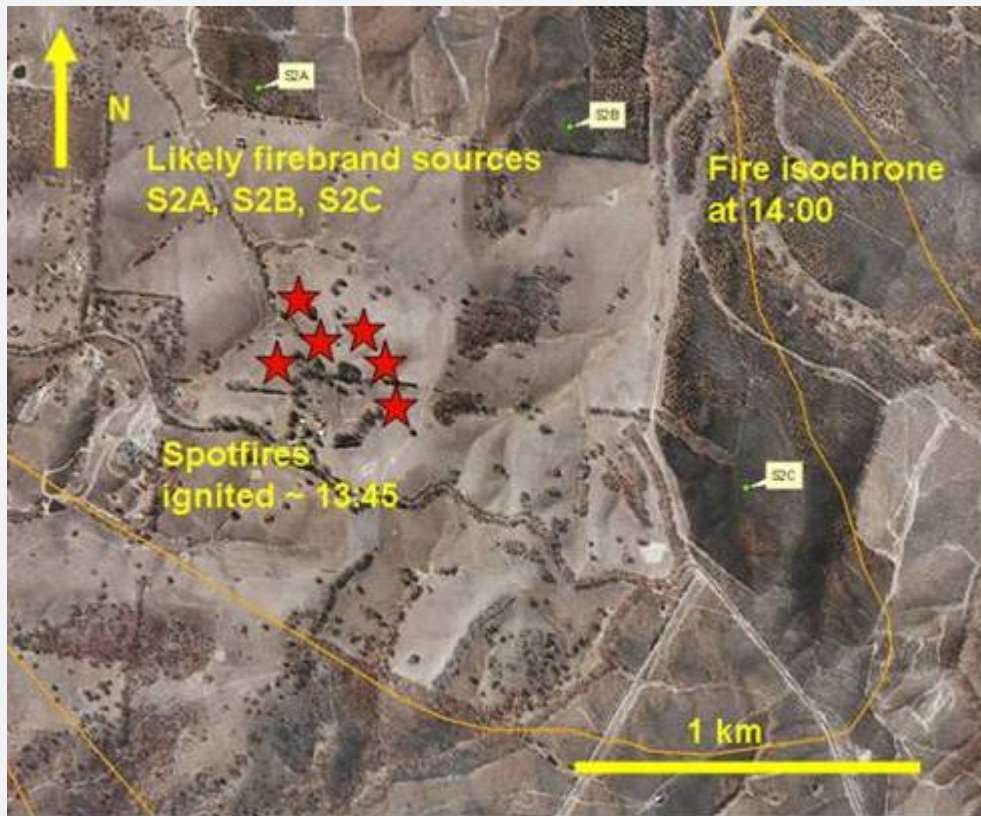
4. Black Saturday spotting – Kilmore East

(Cruz MG, Sullivan A, Hurley R, Sims N, Gould J, Mattingley G, Wells T, Hollis J. 2010. The Kilmore East Fire: Fuel and Fire Behaviour. CSIRO Client Report CES/BDA001)

Significant information for spotting

- wind, vegetation type, over-storey species, topography, plume
- spotting location, time, allow identification;
- source (topo, crown scorch, species)
- distance, travel speed
- likely lofting height
- likely range of terminal velocity
- conclusions about firebrands

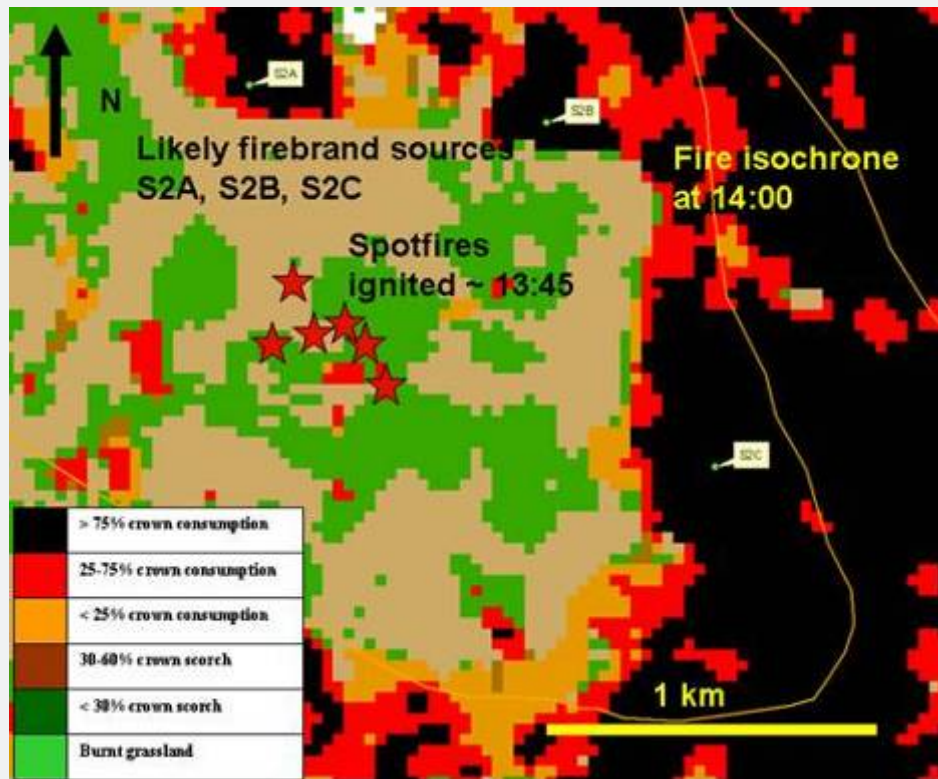
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Information

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- spotting **location**, **time**, allow identification;
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- **distance**, travel speed
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- likely range of terminal velocity

4. Black Saturday spotting – Kilmore East



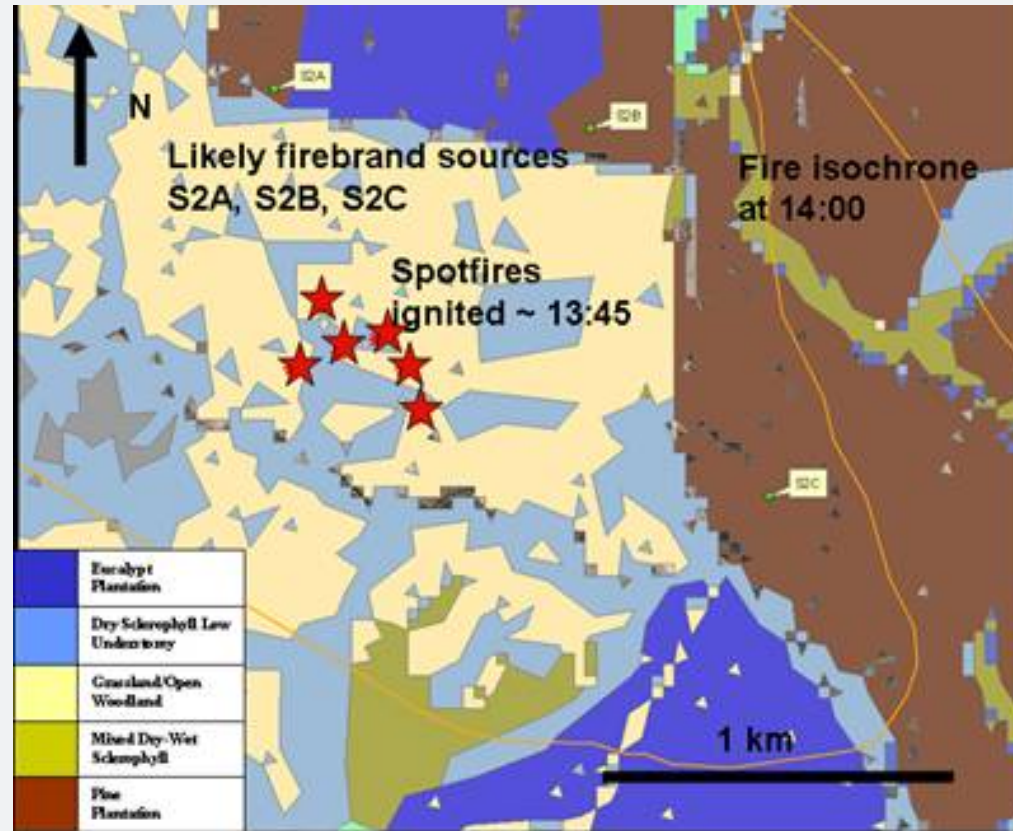
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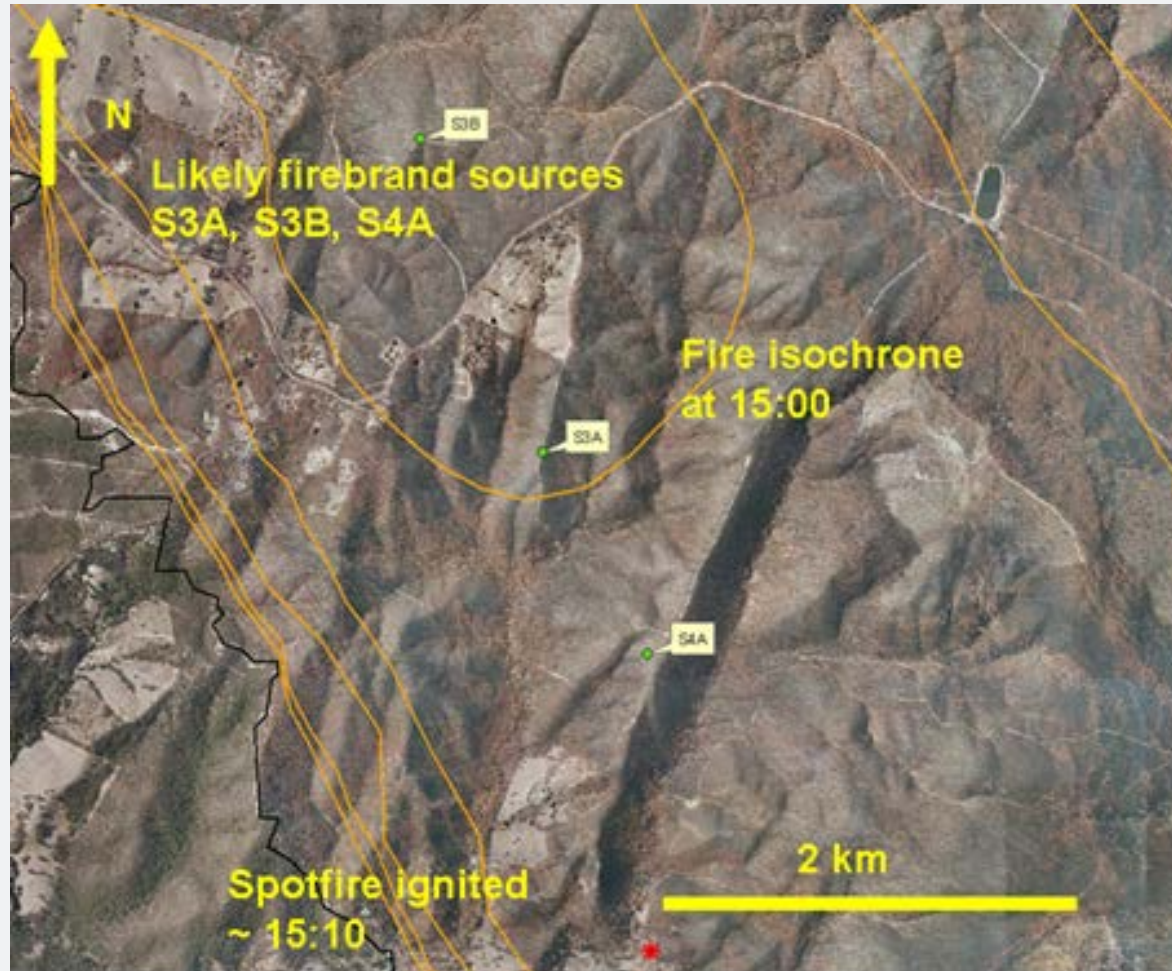
4. Black Saturday spotting – Kilmore East

Information

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- distance, travel speed
- likely lofting height
- likely range of terminal velocity



4. Black Saturday spotting – Kilmore East



Measured firebrand characteristics - 1

Vegetation type	Species/Morph.	Type	Shape	Notoriety (potential, distance)	Ignition type	ν_t (m s ⁻¹)	t_B (min)	Ignition probability
DSFL	<i>E. dives</i> /bark	pepp.	flake	mod.-high, to 4 km, ^{3 13}				
	<i>E. radiata</i> /bark			mod.-high, to 4 km, ^{3 13}				
	<i>E. obliqua</i> /bark	str.		v. high, to 4 km, ^{3 13 18}	complete	3-6, ⁶	0.5-4.0, ⁶	high, ⁸
	<i>E. macrorhyncha</i> /bark			v. high, to 4 km, ^{3 13}				
	DSFD	<i>E. dives</i>						
<i>E. radiata</i>								
<i>E. mannifera</i> /bark		gum	flake					

Measured firebrand characteristics - 2

					Ign	t _v	t _B	Prob
PP	<i>P. radiata</i> /cone	pine		mod, to 2 km, ¹²				
	<i>P. radiata</i> /bract			mod, to 2 km, ¹²				
	<i>P. radiata</i> /needle bunch			mod, short, ¹²				
EP	<i>E. globulus</i> /bark	gum	cyl., 20 mm dia.	?, to 6 km+, ¹²	one end	6+, ₆	4, ₆	
			flake		complete			high, ₉
MDWSF	<i>E. cypellocarpa</i> /bark	gum	flake					
	<i>E. obliqua</i>							
	<i>E. globulus</i>							
Riparian	<i>E. obliqua</i>							
	<i>E. viminalis</i>	gum	cyl.	?, to 6 km+, ^{12 13}				

Measured firebrand characteristics - 3

				Ign	t _v	t _B	Prob	
Miscellaneous	<i>P. pinaster</i> /timber (cylinders of length to diameter of 3:1)	pine	cyl.8 mm dia.		complete	6, 19 20	< 1, 19 20	
			cyl.12 mm dia.		complete	10, ²⁰	3, ²⁰	
			cyl.15 mm dia.		complete	12, ²⁰	5, ²⁰	
	<i>P. pinaster</i> /cone	pine			complete	21, ²⁰	9, ²⁰	
	<i>P. pinaster</i> /cone bract				complete	4, ²⁰	2, ²⁰	v. low, 9
	<i>P. elliottii</i> /cone					13, ⁴		
	Charcoal cylinders (length to dia. 3:1)		cyl.6 mm dia.		complete	8, ²⁰	6, ²⁰	
			cyl.15 mm dia		complete	12, ²⁰	14, ²⁰	

Firebrand transport conditions

1. low plume angle, lofted height 5000+ m, plume updrafts 10-22 m s⁻¹
2. wind speeds 15-25 m s⁻¹, transport times 30 min
3. descent times 15 min plus

Firebrand terminal velocities

1. < 10 m s⁻¹
2. probably, < 6 m s⁻¹

Likely firebrand morphologies, combustion

1. cylinder of bark, long strip of stringy bark, animal scat
2. glowing not flaming, burning from one end/smouldering

Fuel bed ignition

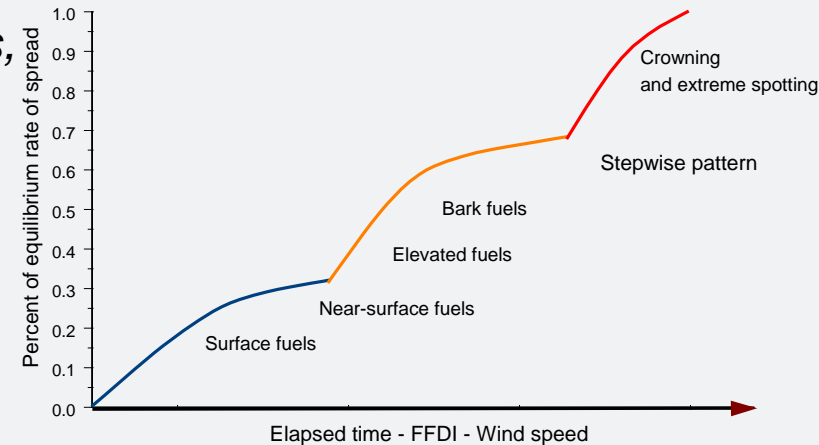
1. Very tiny (< 0.1 g), glowing firebrands can ignite eucalyptus litter
2. Solar radiation influences ignition probability
3. Recently shed leaves are significant
4. Firebrand surface density influences its fuelbed ignition probability, as well as its terminal velocity

Firebrand aerodynamics and combustion

1. The burnout time of long, glowing cylinders of 'ribbonbark/candlebark' at their terminal velocities depends on their degree of internal convolution
2. Some can burn for 20-30 minutes
3. Long strips of 'stringybark' can similarly burn slowly from one end
4. (Charcoal and animal scat can make effective firebrands)

This project deals with:

- *the rate of growth in area and perimeter within the first hour or so from point ignitions, and*
- *the change in rate of spread from time of ignition until an equilibrium spread rate has been achieved,*
- *determining factors involved in transition from moderate intensity flames in surface fuels to high intensity fires that involved multiple layers of fuels (Miguel Cruz)*



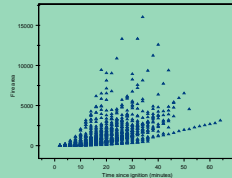
Research Plan

Applications



- Prescribed burning
 - improved burning guides, ignition pattern
- Fire suppression
 - pre-suppression and suppression planning, fire fighter safety, burning operations

Research activity

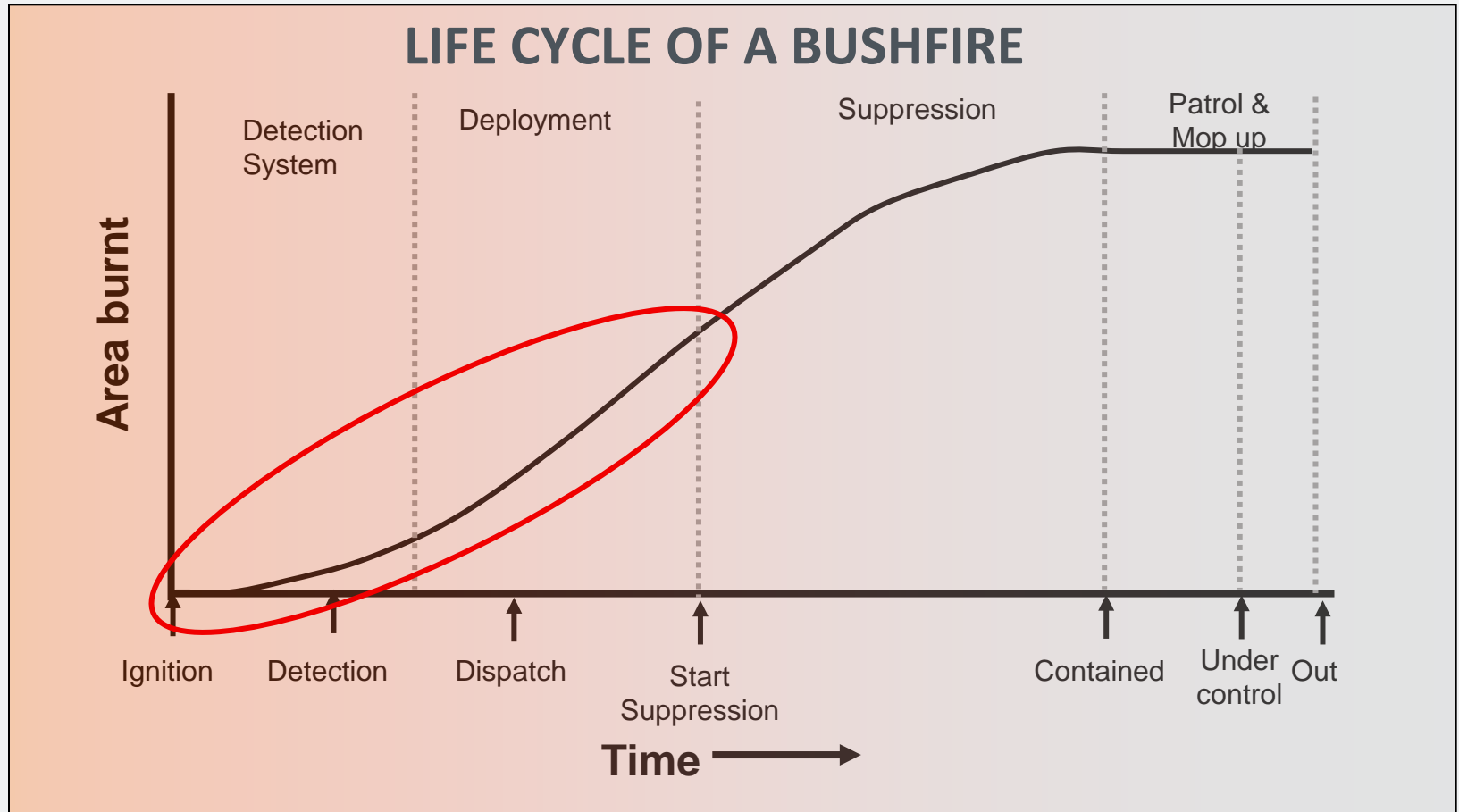


- Data analysis, modelling
- **Literature review**
- **International collaboration (CFS)**
- New research (lab/field experiments?)

Archive data

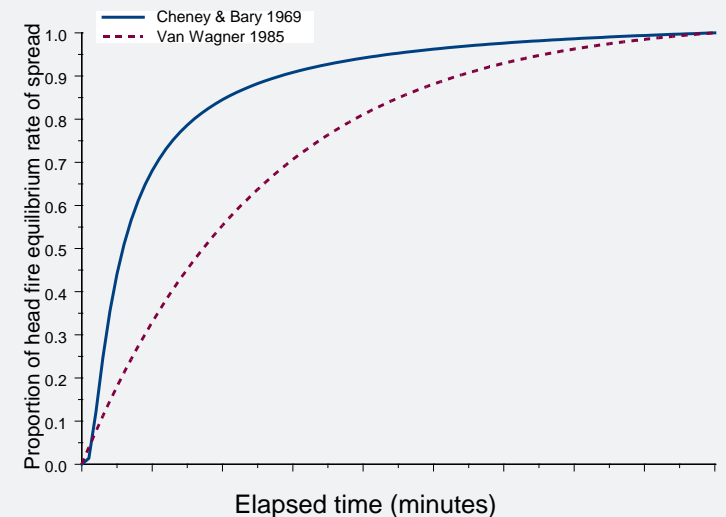
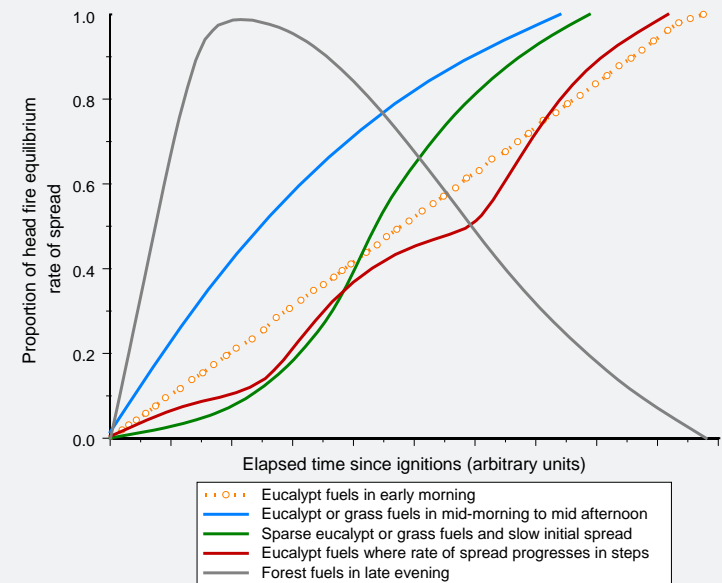


- **McArthur's original experimental data (1950 – 1970) over 300 fires**, WA experimental data (1960s)
- **Project Aquarius, Vesta, other experimental fires**
- Wildfire data- CSIRO, published and unpublished reports from end users



Literature scan

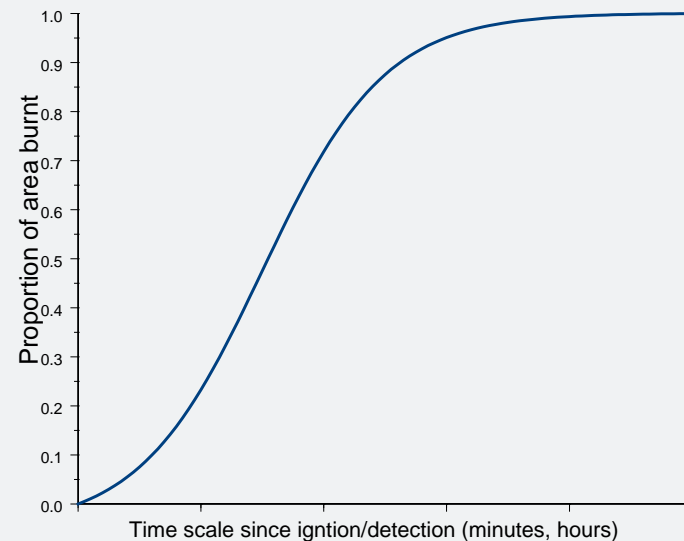
- Show (1916)- more favourable burning conditions, rapid spread tends to burn with acceleration
- Curry and Fons (1938)- wind speed > 3 km/h (burning periods < 22 minutes in pine needles)
- Kerr *et al.* (1971) conceptual theory and several idealised curves
- Luke and McArthur (1978)- proposed a family of possible acceleration curves
- Cheney and Bary (1968)- and van Wagner (1985) proposed theoretical acceleration models
- McAlpine (1983)- fitted empirical data from wind tunnel to Cheney & Bary, and van Wagner (burning periods < 16 minutes in needles and excelsior fuel)



Literature scan

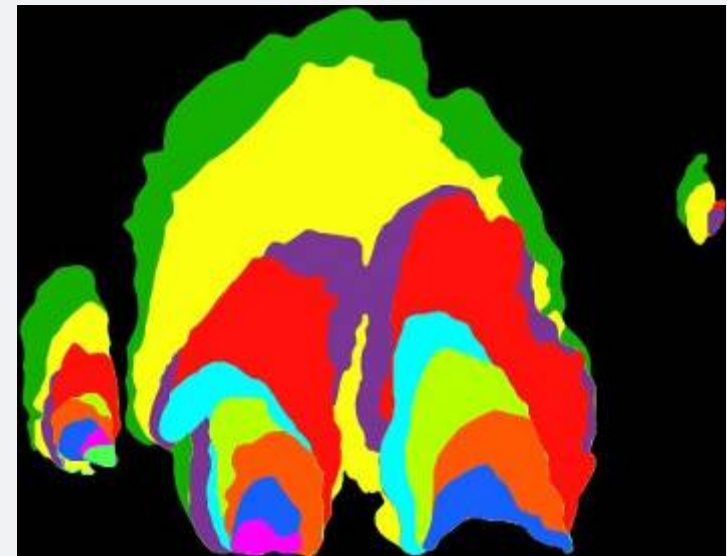
- Cheney and Gould (1995)- effects of head fire width on fire spread and acceleration in grassfires
- McRae (1999)- fire growth model, using predicted equilibrium fire spread (burning periods <25 minutes in pine slash)
- Richards, Richards & Bryce (1990, 1994)- algorithm for simulation the spread of fire perimeter
- Finney (1998 – 2007)- fire simulation growth modeling growth model
- Lavoue *et al* (2007)- simple fire growth (area) parameterisation model from selected wildfires
- Sullivan (2009)- review of simulation and mathematical fire models
- Finney and McAllister (2011) review of fire interactions- discussion on fire growth and length of fire front

Fire growth parameterisation model



Summary:

- Time for a point source fire to reach an equilibrium ROS:
 - 5 – 10 minutes for fine grassy fuels (Chandler *et al* 19983)
 - >60 minutes for heavy slash fuels (Chandler et al 1983)
 - Acceleration patterns are extremely variable, generally the more severe the burning conditions the longer a fire will take to reach equilibrium
 - McAlpine (1988) and Forestry Canada Fire Danger Group (1992) time to reach equilibrium rates were constants for each type tested despite different fire conditions
 - Majority are: theoretical and small scale empirical studies
 - **YET:** no scaling laws have been developed that will enable to predict growth and time to equilibrium ROS from ignition



Data

•Laboratory and other experiments

- McAlpine (1988) (27 fires, up to 16 minutes, max distance travelled 4.95 m)
- Canadian Forest Service small scale point-source (collaboration with CFS-Mike Wotton)

•Existing field experiments:

•McArthur 1950s – 1970s data

- Small experiment fires (46 fires up to 8 minutes, max distance travelled 13 m)
- Black Mountain experiments (136 fires, up to 64 minutes, max distance travelled 71 m)
- Data reduction in progress:
 - Kowen experiment (control burning guide experimental data)
 - 2 Victorian sets of experiments
 - WA experimental data- collaboration with DEC, WA

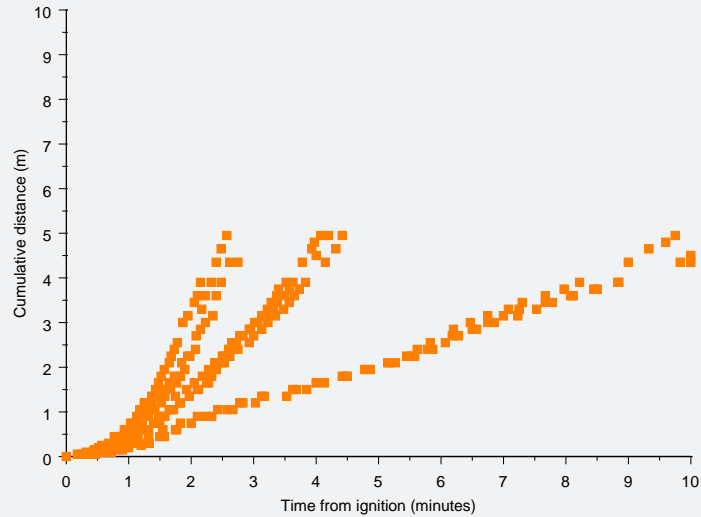
•Large scale experiments:

- Project Aquarius and Project Narrik- (32 experimental fires, up to 250 minutes, max distance travelled 1175m)
- Project Vesta (110 experiments, up to 70 minutes, max distance travelled 1175 m)

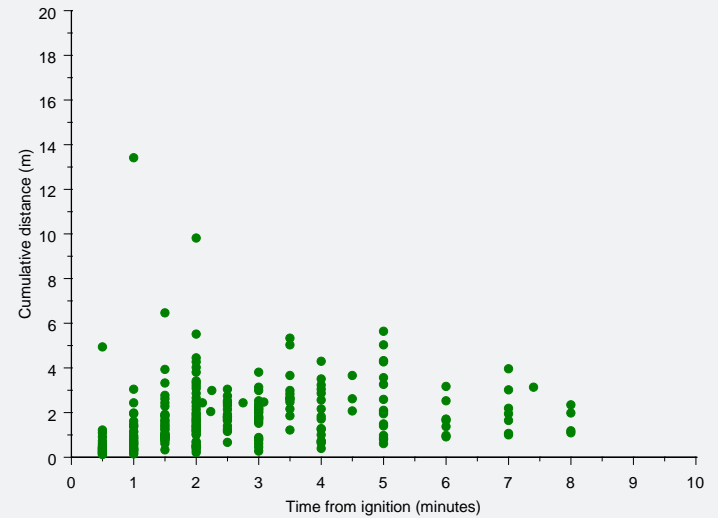


Fire growth

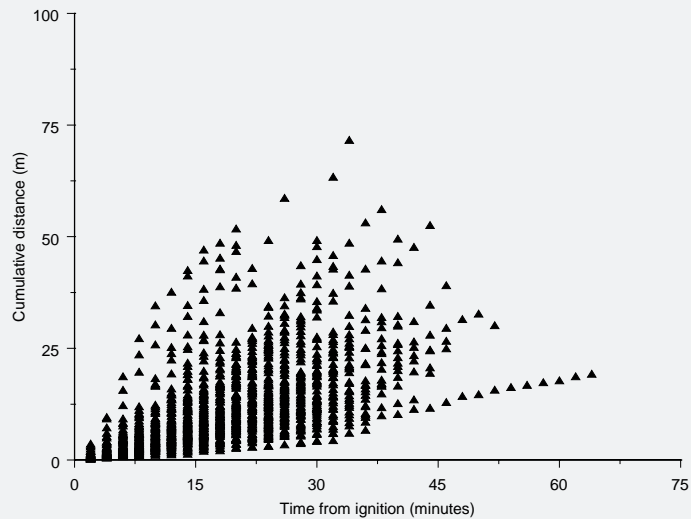
Wind tunnel point-source ignition experiments (McAlpine 1988)



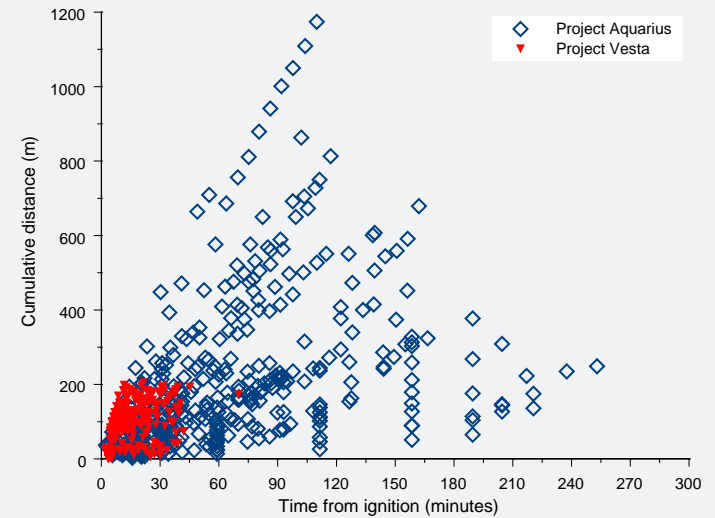
Kowen point-source ignition small scale experiments



Black Mountain point-source ignition experiments

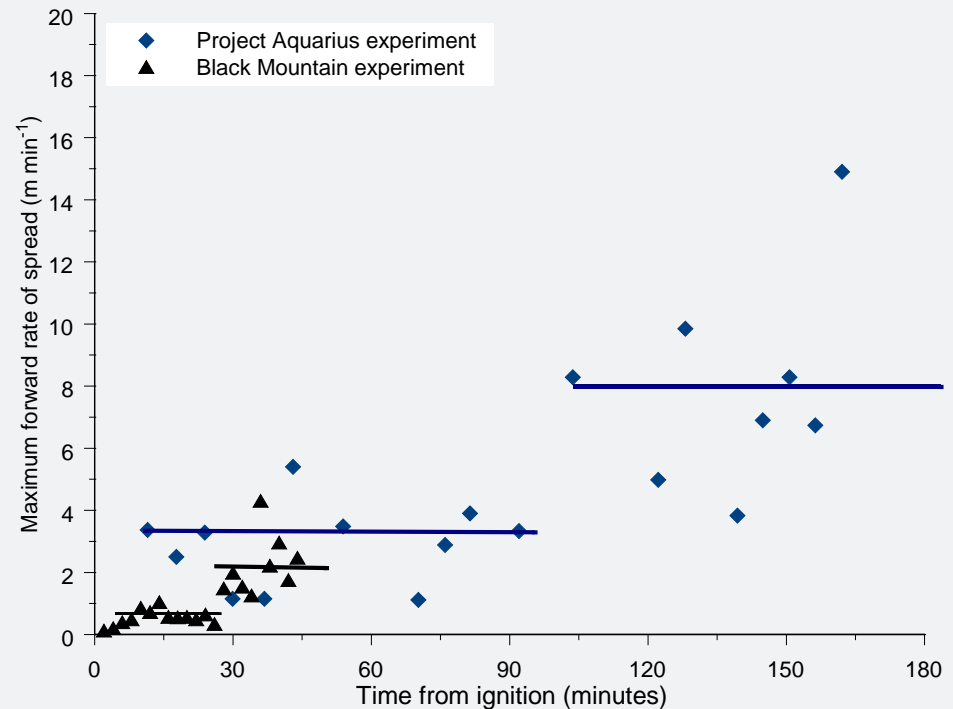


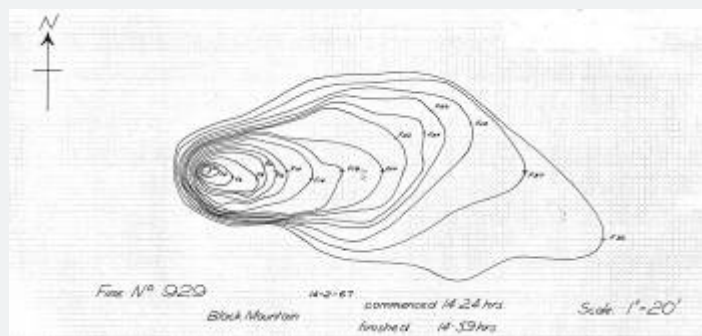
Large scale field experiments



Factors contributing to acceleration:

- fuel moisture
- fuel structure, characteristics, distribution
- wind speed and turbulence at the flaming zone
- slope
- burn out time
- scaling up of fires
- convection column – does or does not form
- ?????





Progress and tasks

1. Collating CSIRO archive experimental fires into data base
 - a) Experimental fires,
 - b) Historical weather records (BoM),
 - c) Other experimental fires (DEC, WA)
2. Literature review on fire growth (cond't)
 - a) Pre 1990's- point source to equilibrium area, perimeter & fire spread;
 - b) Present- fire growth simulators, e.g. Phoenix, FARSITE
3. International collaborations
 - a) Joint research program with Canadian Forest Service
4. Developing a research plan
 - a) Data acquisition and analysis,
 - b) Identified data gaps,
 - Experimental plan
5. Model evaluation and application
 - a) Fire behaviour knowledge base

FIRE LOAD AND SUPPRESSION RESOURCING

(Matt Plucinski)

Topic areas:

- Fire occurrence
- Productivity and response
- Resource allocation models

RESOURCE ALLOCATION MODELS

(Fire load and suppression resourcing)

- Tools for:

- Identifying the optimal mix & number of resources
- Predicting effects of policy & budget changes
- Comparing resource types
- Predicting resource requirements in a changing environment

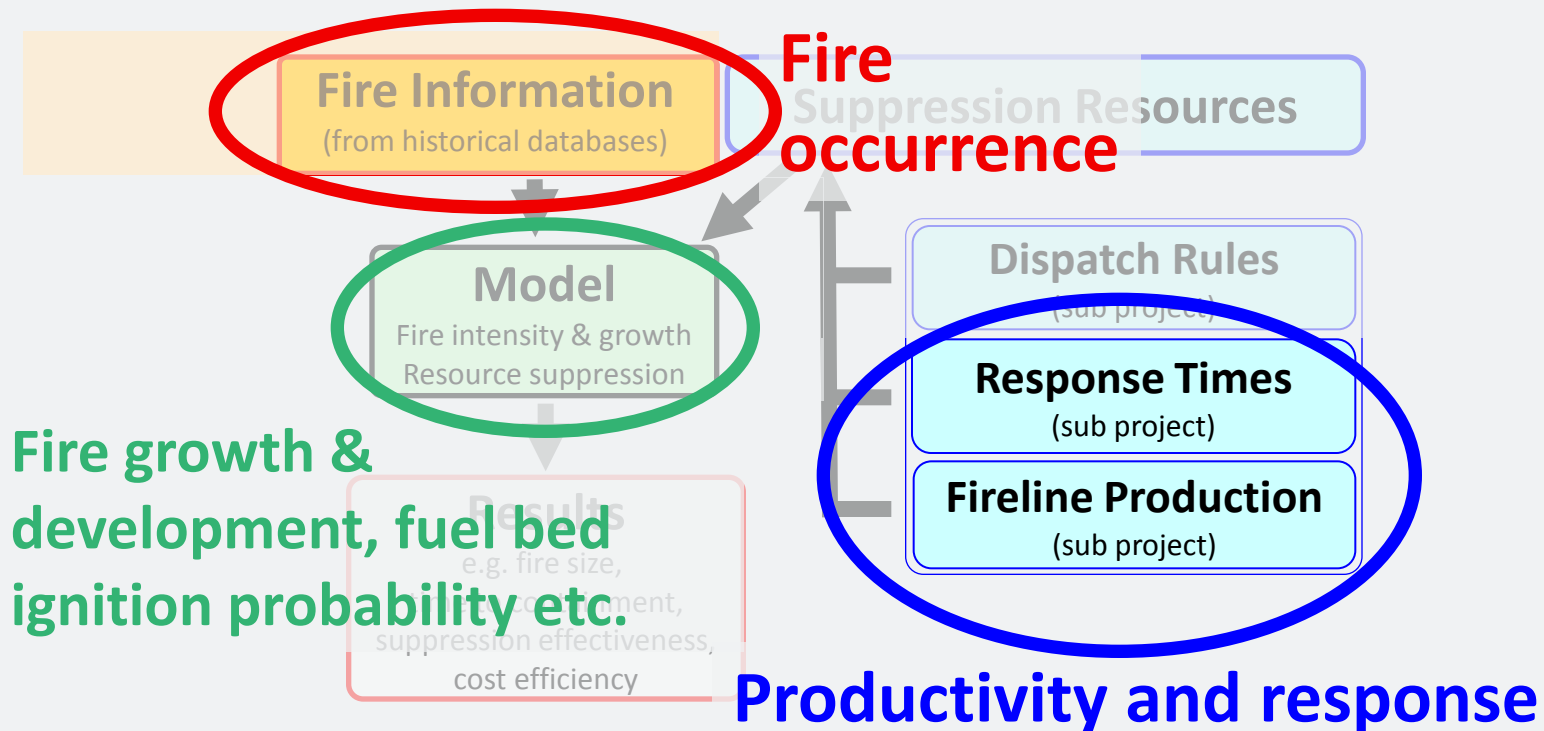
- This project:

- Literature review (current work)
- Framework (end of project)

RESOURCE ALLOCATION MODELS

(Fire load and suppression resourcing)

Components



PRODUCTIVITY AND RESPONSE

(Fire load and suppression resourcing)

What:

- Develop productivity and response models for different resource types

Why:

- Compare resource types under different scenarios and environmental conditions
- Determine important parameters affecting resource performance



PRODUCTIVITY AND RESPONSE

(Fire load and suppression resourcing)

How:

- Expert elicitation
- Resource tracking

Masters student project(s)



FIRE OCCURRENCE

(Fire load and suppression resourcing)

- The presence and quantity of ignitions across spatial and temporal scales
 - Map ignition risk
 - Investigate fire cause factors
 - Develop predictive models
- Significant amount of international research
 - Regional case studies
 - Consider different ignition causes separately

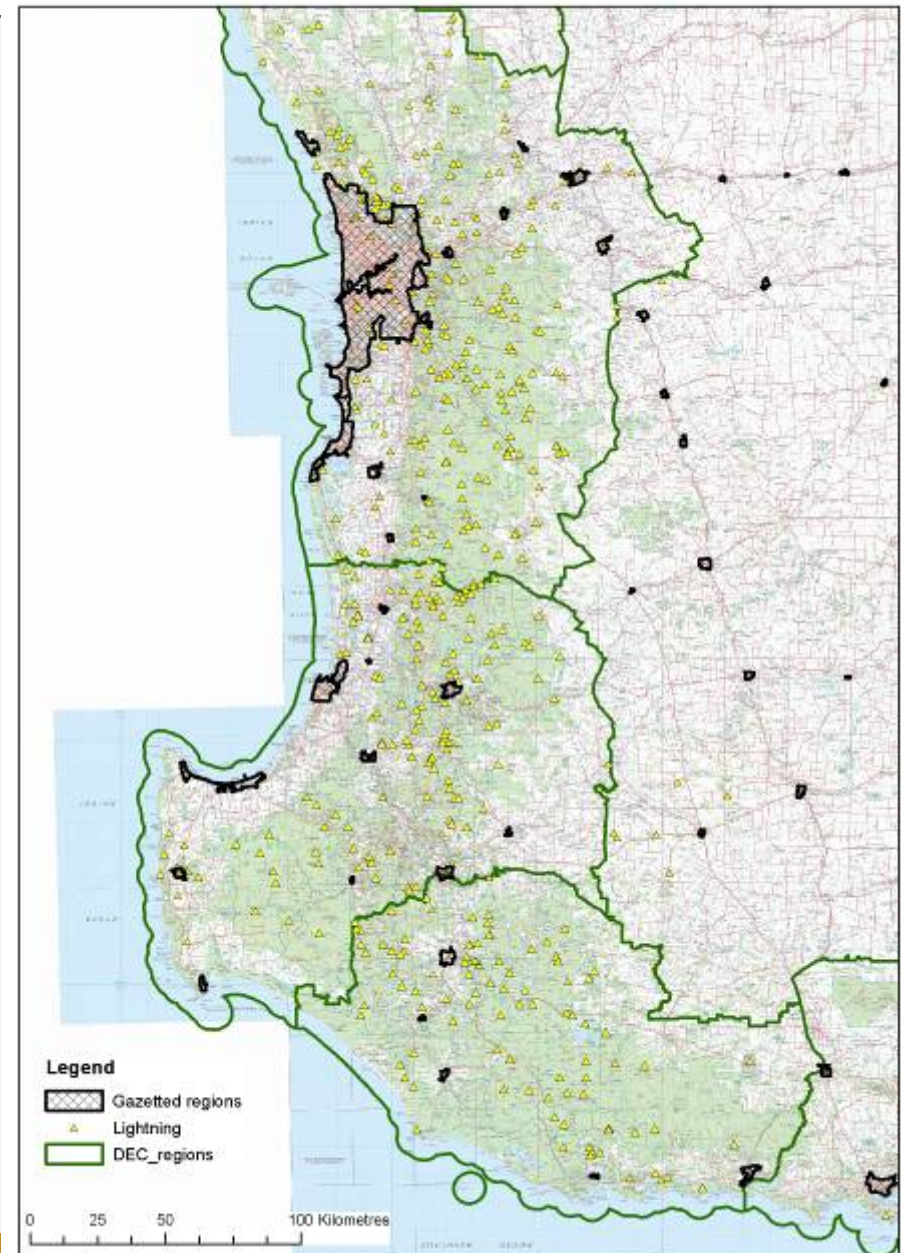
FIRE OCCURRENCE

(Fire load and suppression resourcing)

- Workshop

Case study: South west WA

- FESA & DEC fires
(Work in progress)
- Location by cause
 - Deliberate (arson)
 - Accidental
 - Lightning

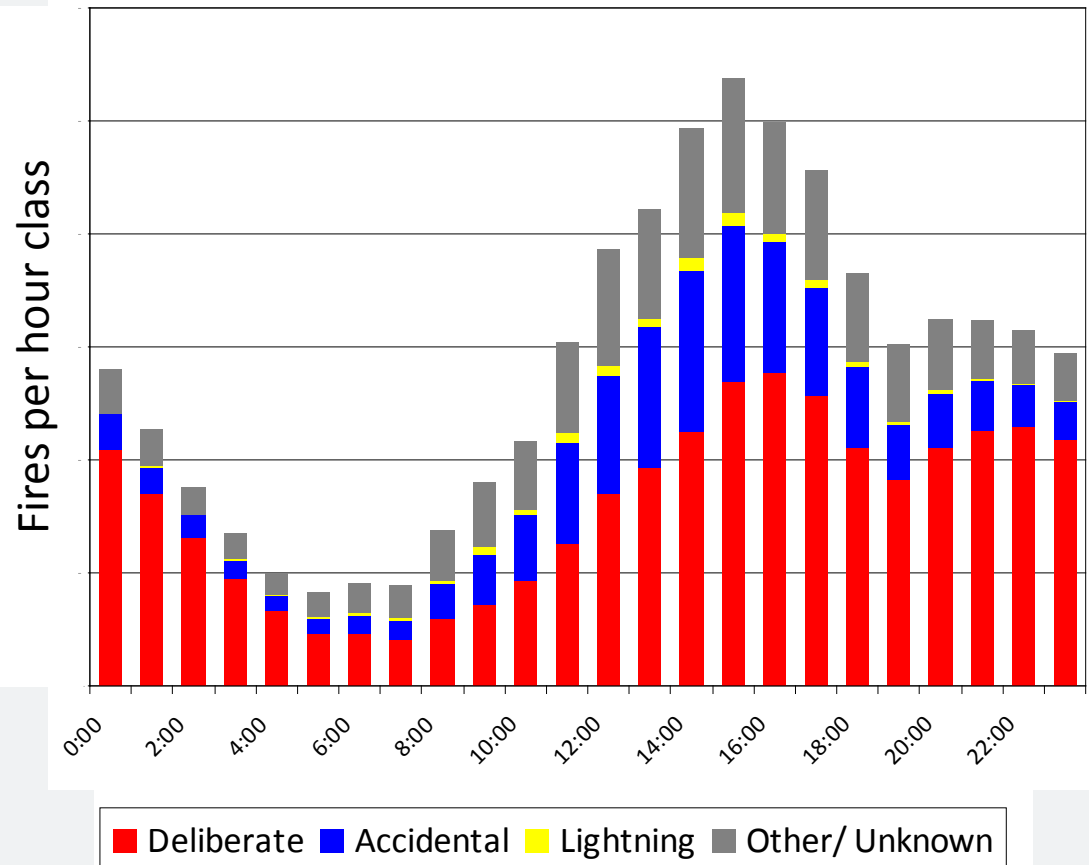


FIRE OCCURRENCE

(Fire load and suppression resourcing)

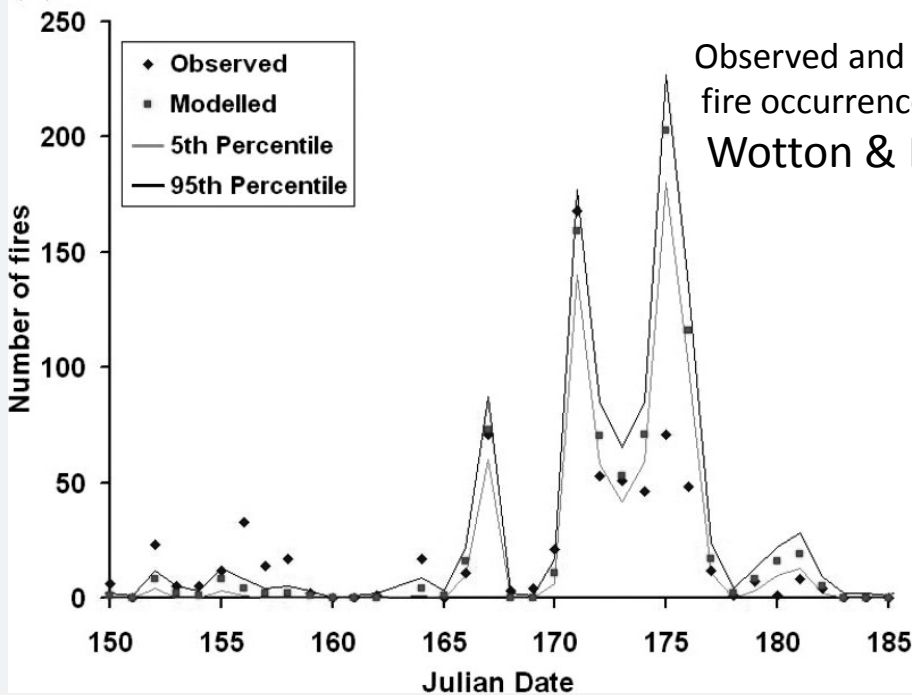
Case study: South west WA

- FESA & DEC fires
(Work in progress)
- Timing
 - Season
 - Month
 - Day of week
 - School days
 - Work days
 - Time of day

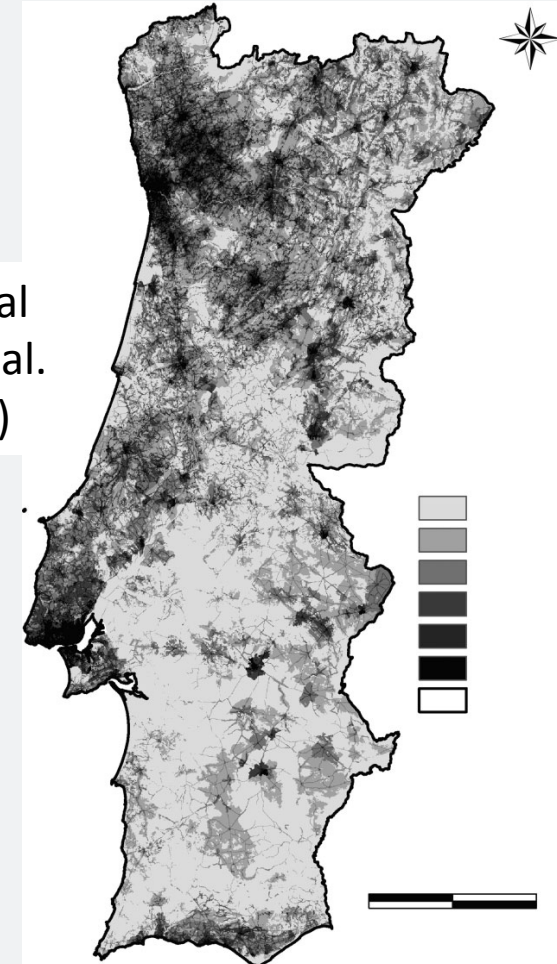


FIRE OCCURRENCE

(Fire load and suppression resourcing)



Portugal
Catry et al.
(2009)



- Long-term goals
 - Spatial models – ignition risk maps
 - Temporal models - operational applications
 - Fire load prediction (incorporating fire growth and initiation models)

Topics:

- Fire occurrence
- Productivity and response
- Resource allocation models