bushfire CRC

REPORT NO. A.07.03

FIRE BEHAVIOUR WORKSHOP

STATE OF KNOWLEDGE – AUSTRALASIAN UPDATE

Coordinated by Jim Gould and Miguel Cruz
Bushfire Research Group, Ensis - CSIRO, Yarralumla, ACT, Australia

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CONTENTS

WORKSHOP OBJECTIVES

Fire behaviour- State of knowledge

Australasian Update

18th September – 19th September 2007

Accurate, high-resolution fire behaviour prediction is the key to taking effective management action before and during fires. Fire prediction models need to accurately describe the fire environment and the level of uncertainty in predictions so that fire managers can better understand the consequences of their actions and their interactions with natural events. Reliable predictions of different elements of fire behaviour including rate of spread, intensity, flame characteristics, spotting, fuel consumption and emissions are critical information for decisions about suppression strategies. Over the past 10 years there been many advances in fire behaviour knowledge to provide better prediction systems for eucalypt, exotic pine plantation and shrubland fuel types. This symposium will present the state of knowledge of fire behaviour in Australasian fire behaviour models from the current research findings of Project Vesta, Project FuSE, spot fire modelling, fuel moisture dynamics and fire weather. The symposium will address the development, implementation and evaluation of fire behaviour models with a focus on operational applications.

WORKSHOP PROGRAM

18th September

13:00	Opening
13:15	Fire Behaviour vs. Fire Danger: Importance and Application
	Keynote speaker: **Phil Cheney**
14:00	Fire weather
	National perspective- new services and products
	Graham Mills
	Regional perspective- operational forecasting:
	Mika Peace
15:00	Afternoon tea
15:30	Fuel moisture modelling: **Stuart Matthews**
16:15	Fire behaviour modelling:
	Empirical approach: **Wendy Anderson**
	Physical approach: **Andrew Sullivan**
17:15	Close for the day

19th September

7:30	Breakfast (room to be announced)
8:00	Grassland fire behaviour- overview: **Jim Gould**
8:30	Eucalypt forest fire behaviour- Project Vesta results
	Phil Cheney, **Jim Gould**, **Lachie McCaw**
	Fuel parameters and hazard scoring
	Fire behaviour modelling
	Spot Fire Modelling: **Peter Ellis**
10:00	Morning tea
10:30	Eucalypt forest fire behaviour (continue)
	Model validation
	Operational applications
11:30	Shrubland fire behaviour- Overview: **Wendy Anderson**
	Project FuSE- New Zealand Update: **Grant Pearce**
	Project FuSE- Australia Update: **Miguel Cruz**

12:30	Lunch
13:30	Plantation fire behaviour: **Miguel Cruz**
14:15	Operational application of simulation modelling (Keynote speaker: **Mark Finney**)
15:00	Afternoon tea
15:30	Application of fire behaviour modelling for risk management: **Kevin Tolhurst**
16:00	Bushfire CRC fire simulation model: **George Milne**
16:30	National Fire Behaviour Prediction Systems: **Jim Gould**
17:00	Closing

FIRE BEHAVIOUR VS. FIRE DANGER: IMPORTANCE AND APPLICATION

Phil Cheney
Honorary Research Fellow, CSIRO
Yarralumla, ACT

Abstract:

It is important to distinguish between predictions of fire danger and fire behaviour. The systems are designed for different purposes and so at different relationships between common variables that are not necessarily compatible.

The conceptual definition of fire danger is impossible to quantify as it contains both tangible and intangible variables. A fire danger rating system uses selected variables to produce an index that reflects the management needs. Usually, fire danger rating is an estimate of burning conditions over a large area, usually for a generalised fuel type and often for a particular time of day.

A fire behaviour prediction is an estimate of the rate of spread and other fire behaviour characteristics for a particular fire over some time period, usually the next the work period. A fire behaviour forecast is specific and requires specific imports for fuel weather and typography for the localities of the expected fire travelled.

In this session we discuss the fire danger rating systems used in Australia and their function in relation to the new fire spread algorithms produced by the Vesta research.

Suggested reading:

Chandler, C.; Cheney, P.; Thomas, P.; Trabaud, L.; Williams, D. 1983 Fire in Forestry Vol.1: Forest Fire Behavior and Effects John Wiley & Sons, New York 450 pp.

Chandler, C.; Cheney, P.; Thomas, P.; Trabaud, L.; Williams, D. 1983 Fire in Forestry Vol.2: Forest Fire Management and Organization John Wiley & Sons, New York.

Cheney, N.P. 1991. Models used for fire danger rating in Australia. In: Cheney, N. P; Gill, A. M., (eds). Proceedings of Conference on Bushfire Modelling and Fire Danger Rating Systems, 11-12 July 1988, Canberra, CSIRO Division of Forestry and Forest Products, Yarralumla, pp.19-28.

Luke, R.H., McArthur, A.G. 1978. Bushfires in Australia. Aust. Goverm. Publishing Serv. Canberra, ACT. 359 p.

Fire Danger Rating
or
Fire Spread Prediction

Phil Cheney Honorary Research Fellow

CSIRO
Bushfire Behaviour and Management

Outline

- Purpose
- Definitions
- Simple or complex systems
- Australian systems
  - Historical and cultural background
  - Designing for "worst possible"
- Application of Fire Danger Rating
- Separation from fire spread prediction
- Future Needs

2

Purpose – What do you want to do?

Fire management systems reflect the socio-political attitude to fire.

- Exercise total control over public use of fire?
  - Death penalty (e.g. China)
- Exercise partial total control?
  - Prohibited burning periods - permits
- Foster flexible co-operative use and control of fire?
  - Fire Danger Rating systems
- Predict Fire spread?
  - Fire behaviour guides / tables

3

What is Fire Danger?

Fire danger is the sum of all factors that affect the ignition, spread, and difficulty of control of fires, and the damage they cause.

- All potentials must be present: e.g.
  - No chance of ignition, no fire danger;
  - No fuel, no fire danger;
  - No value to damage, no fire danger.

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Fire Danger Factors

- Variable fire danger factors
  - Change rapidly with time but may apply over wide areas, e.g. weather variables.
- Constant fire danger factors
  - Change slowly with time but my vary widely from place to place, e.g. topography, fuel, assets of value.
- The total concept of fire danger is impossible to embody in a single, practical index.

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Fire danger rating

A fire management system that integrates the effects of selected fire danger factors into one or more indices of current protection needs

Systems can range from simple to highly complex

6

Fire Danger – management needs

What do you want the system to do?

- Warn public when ignition is likely?
  - **Ignition index (hazard sticks).**
- Warn public and firefighters of dangerous weather when fires are difficult to control?
  - **Fire weather indices.**
- Set priorities on where fire management effort should concentrate?
  - **Wildfire threat analysis.**
- Predict fire behaviour at a particular point?
  - **Fire behaviour guide.**

7

Ignition Indices

- Predict the ease of ignition in a standard forest fuel.
- Depends primarily on the moisture content of the fuel.
- Predict the moisture content of the fine fuel
  - From the moisture of wooden rods.
  - From air temperature and relative humidity.
  - From direct measurements of fuel moisture.

8

West Australian hazard scale (1944)

General scale	Empirical scale	Temp(°F)	RH (%)
Nil	0-1	<64	>68
Low	1-4	64 – 80	32 – 68
Moderate	4-6	69 – 86	26 – 61
Average summer	6-7	78 – 94	21 – 51
High Summer	7-8	80 – 97	16 – 45
Severe Summer	8-9	87 – 99	17 – 30
Dangerous	9-10	> 92	<27

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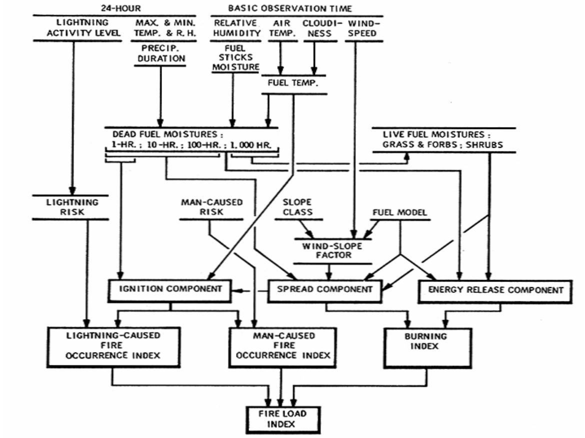
US National Fire Danger System



Australian fire danger systems

- There are two fire danger systems in use in Australia for the dominant fuel types: grasslands and forests
- Each system provides a relative measure of the difficulty of suppression for a commonly found fuel condition in level topography.

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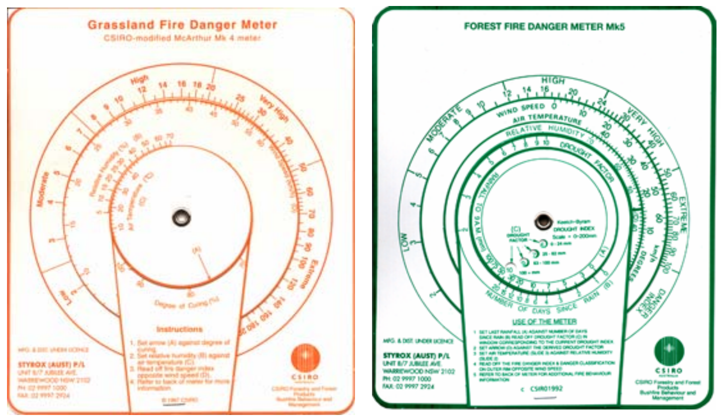

Background

- Wide spread use of fire in the country
  - Clearing for agriculture,
  - Agricultural and forestry burning
  - Cooking and warmth in the open.
- A small scattered population
  - Volunteer firefighters (farmers, rural landowners)
  - Part-time forest firefighters (forestry officers &staff)

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Background – rationale

Australia needed a system that:

- Recognised the need to use fire in the country.
- Provided warning of weather conditions when fires would be difficult to control.
- Minimised the disruption to forestry, farming and other rural activities.

The system needed to be based on the behaviour of rural fires.

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Planning for "worst possible"

A fire danger rating system should be designed so that the upper end of the scale represents the most severe fire weather ever recorded.

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"Worst Possible" conditions

- Scale – 0 - 100
- 100 represented the worst recorded conditions : Victoria, 13 January 1939
  - Severe summer drought
  - Temperature 40°C
  - Relative Humidity 10%
  - Mean wind speed 45 Km /hr

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Australian fire danger systems

Two systems were needed because the fuels react differently to weather variables

Weather factor	GFDM	FFDM
Drought	Grass curing	Drought index
Rainfall	Not considered	Drying curves
Temperature & relative humidity	Moisture content reaction similar in both fuels	
Wind speed	Similar relationship but relatively more important than fuel moisture in grassfires than in forest fires	

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Australian fire danger systems

- Based on a large number of experimental fires and observations on wildfires.
- Each fire was measured for rate of spread and rated for difficulty of suppression.
- Used for public warning and setting the resources required for suppression on a daily basis for 30 years.

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Fire Danger Rating

- Fire danger rating
  - an expert assessment of the difficulty of suppression of a fire.

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Fire Danger	Max flame height (m)	Suppression Options
Low	0.5	Easy. Stopped by tracks.
Moderate	1.0	Easy with water.
High	3.0	Difficult with water.
Very High	4.0	Possible only light fuels and favourable topography.
Extreme	6.0+	Impossible at the head. Possible on flanks.

Fire Danger	Max flame height (m)	Suppression Options
Low	1.5	Easy. Hand tools.
Moderate	6.0	Upper limit for bulldozers, air tankers
High	15.0	Possible in light fuels and on lee slopes.
Very High	15.0 +	Possible only as fire starts (i.e. very small).
Extreme	30.0 +	Impossible.

Implementation of FFDM

Fire Danger Index Range	Fire Danger Rating	Preparedness Level
0 – 5	Low	➢ No special arrangements
5 – 12	Moderate	➢ Key fire towers manned
12 – 24	High	➢ Fire units (tankers) available in 30 mins ➢ Light units in field
24 – 50	Very High	➢ Supplementary fire towers manned ➢ Fire permits cancelled ➢ Heavy-duty units (large tankers and dozers) at work site, available in 15 mins
50 +	Extreme	➢ Total fire ban ➢ All public lands closed ➢ Workforce on standby at depot ➢ Light units on patrol ➢ Leave cancelled or on stand-by at home

Fire spread Prediction

- Requires specific information on fuel, weather and topography.
- May require different models for different fuel types.
- Predicts quasi-steady spread for relatively short periods.
- Systems need updating as better algorithms become is available.
- Require specialist training for accurate implementation

25

Separation of fire spread and Fire danger

- Different functions are used to relate the variables to fire spread and suppression difficulty.
  - Windspeed: direct (spread); power (suppression)
  - Curing: sigmoidal (spread); exponential
- Suppression planning requires a broad base
  - Canberra fire example
- Legal Issues
- Historical benchmarking

26

Future Needs?

- Large –urban based population
  - Poor rural underclass
- Little understanding or concern about fire
- Limited use of fire in rural areas
- Political spin doctors
  - Bad management or Gods will?
  - Evacuation or protection of rural settlements?
  - Self-help or prescribed control

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FIRE WEATHER – NATIONAL PERSPECTIVE: NEW SERVICES AND PRODUCTS

Graham Mills
Bureau of Meteorology Research Centre
Melbourne, VIC

Abstract:

The talk will focus on a range of numerical weather prediction model (NWP) based forecast guidance products that have been developed as part of the Bushfire CRC Project A2.1 and which have been integrated into the Bureau's operations. Emphasis will be on the forecast gustiness, the gridded KBDI/SDI drought factors, the fire danger index products available at either 12.5 km spacing (nationally) and 5km spacing over most forest areas at hourly intervals, and the understanding and verification of wind change forecasts – the Wind Change Range Index (WCRI).

Emphasis will be made on the richness of detail and increased understanding of time and space variations seen in these forecasts, and will point to the challenge of best use of these products.

If time permits, I will also touch on the on-going studies of abrupt near-surface drying events, and also on the seasonal bushfire assessment workshops.

Suggested reading:

Huang, X., and G.A.Mills, 2006. Objective identification of wind change timing from single station observations Part 1: methodology and comparison with subjective timings. Aust. Meteor. Mag. 55, 261-274.

Huang, X., and G.A.Mills, 2006. Objective identification of wind change timing from single station observations Part 2: towards the concept of a wind change climatology. Aust. Meteor. Mag. 55, 275-288.

Finkele,K., G.A.Mills, G. Beard,and D. Jones, 2006. National daily grided soil moisture deficit and drought factors for use in prediction of Forest Fire Danger Index in Australia. Aust. Meteor. Mag. 55, 183-197.

(above three available from http://www.bom.gov.au/amm/papers2006.shtml)

Mills, G.A., 2005. On the sub-synoptic scale meteorology of two extreme fire weather days during the Eastern Australian fires of January 2003. Aust. Meteor. Mag. 54, 265-290.

Mills, G.A., 2005. A re-examination of the synoptic and mesoscale meteorology of Ash Wednesday 1983. Aust. Meteor. Mag. 54, 35-55.

Huang, X., and G.A. Mills, 2007. Classifying objectively identified wind changes using synoptic pressure cycles. BMRC Research Report. No 128. 60pp.

Huang, X, and G.A.Mills, 2006 . Objective identification of wind change timing from single station observations. BMRC Research Report No 120. 88pp.

PROGRAM A

Supporting fire weather forecasts with NWP guidance

Graham Mills, Huang Xin-Mei, and Klara Finkele
Bureau of Meteorology Research Centre and Bushfire CRC

bushfire CRC

Australian Government
Bureau of Meteorology

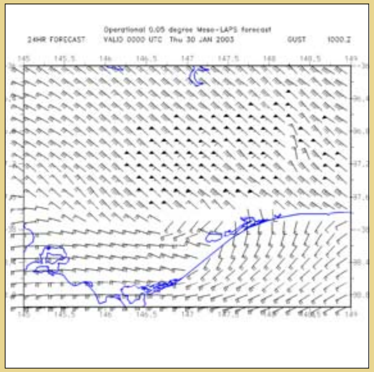
Mesoscale NWP products

- Gusts/wind structures
- Fire danger index guidance
- Wind change guidance and understanding

ALL THESE PRODUCTS ARE OPERATIONAL!

Gusts

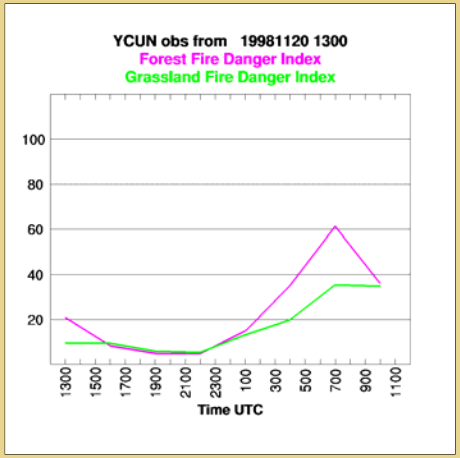
Alpine fires - gusts.ppt



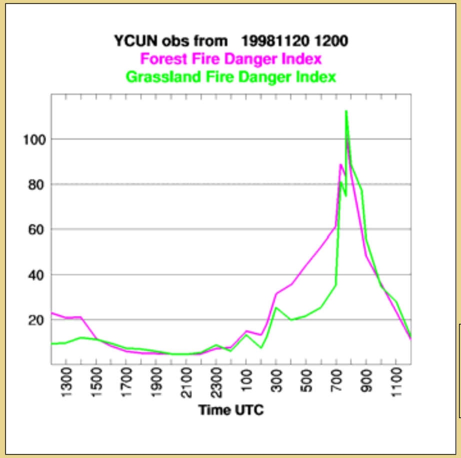
Fire Danger Index

- FFDI/GFDI = f(D, T, RH, V)
- Originally designed as the value "at time of maximum temperature" (due to normal diurnal variations that sort-of works)
- 3pm a proxy for "time of Tmax" due to 3-hourly (at best) observations in 60's and 70's

Synops

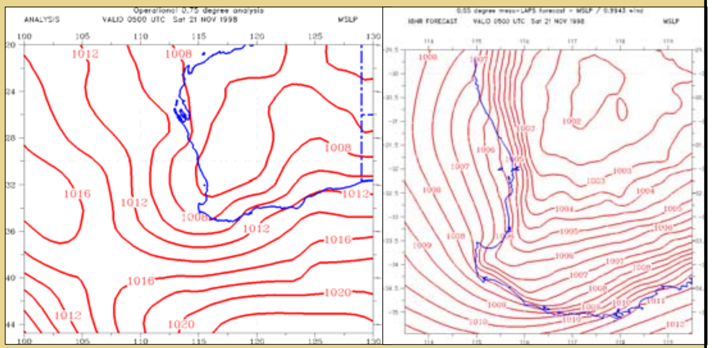


Then came AWS!



Thanks to Richard Rattley

At the same time, mesoscale NWP models are coming on line

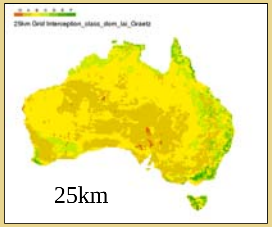


So can we forecast ffdi/gfdi fields?

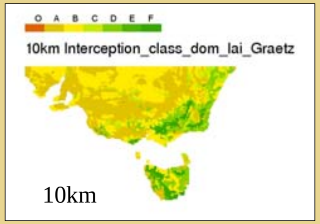
- We have nwp forecast T, RH, V on the grid
- Some of these are biased (esp wind)
- KBDI/SDI are typically calculated at the fire weather stations, using station data
- SDI also requires an "interception class" that was only specified at those station locations
- → Klara's gridded DF project
- Grassland curing estimates are pretty ordinary both in terms of accuracy and spatial cover

Diversion – gridded DF

- Uses 25km/10km daily rainfall analyses and maximum temperature analyses (national/southeast)
- Uses a gridded SDI interception class based on Graetz' vegetation class map

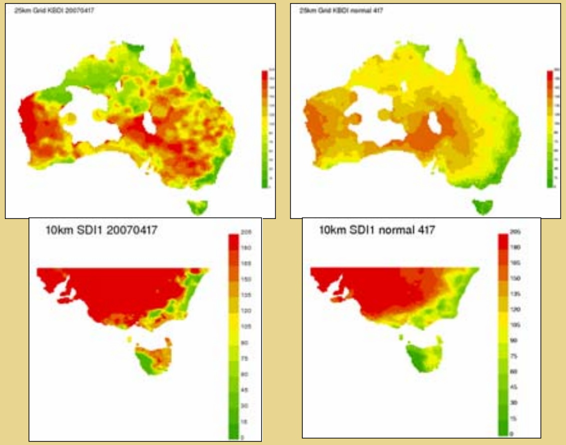


25km

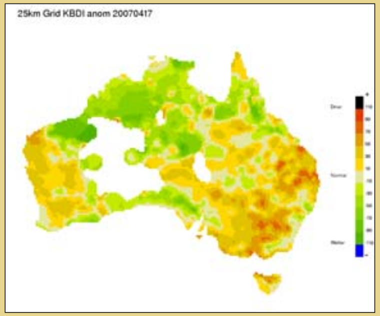


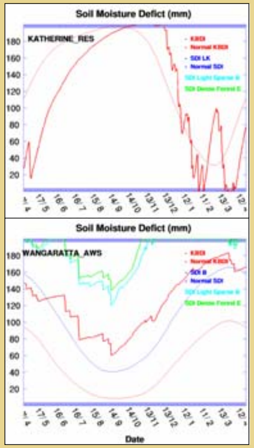
10km

An this leads to, every day



Anomalies, time series



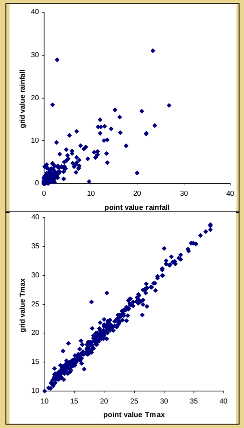


Will this be the same as the SMD values from station data?

- Algorithms identical
- Input data are analyses

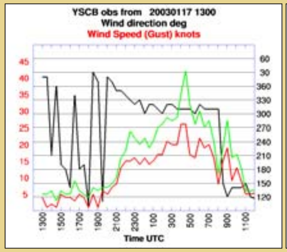
- NO!

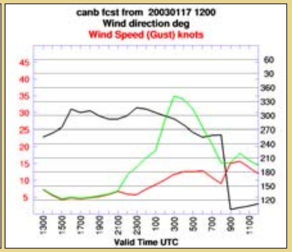
- BUT might be more representative (?)
- Provides input to mesoscale NWP



What to use from the model?

- Temperature – model screen temp
- Dewpoint – model screen TDPT averaged with TDPT at top of mixed layer
- Wind – (30m wind + gust speed)/2.

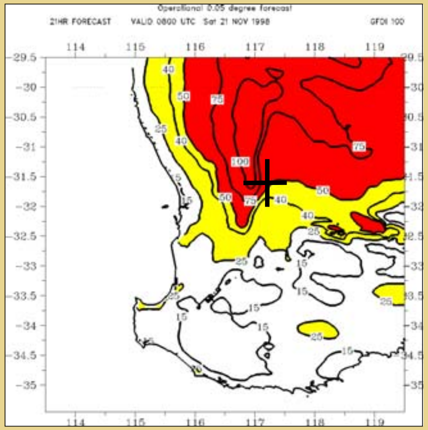




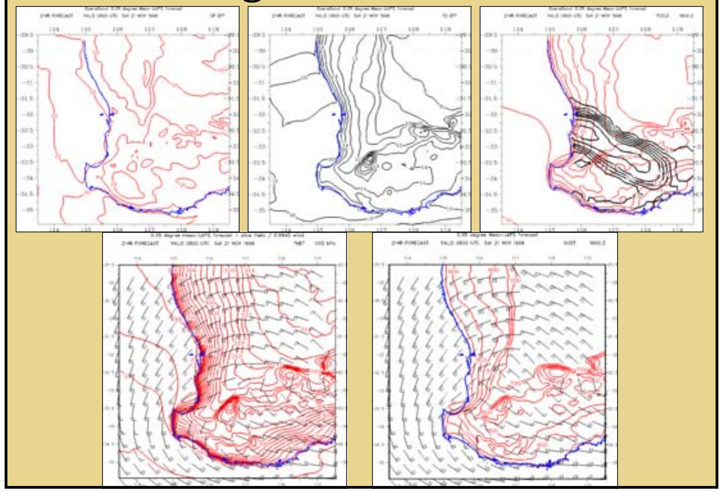
What to use from the model?

- Temperature – model screen temp
- Dewpoint – model screen TDPT averaged with TDPT at top of mixed layer
- Wind – (30m wind + gust speed)/2.
- **Drought Factor – use gridded fields**
  - 25km/10km
  - SDI/KBDI

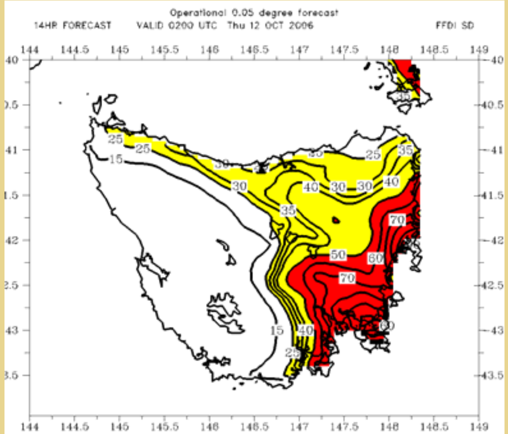
Forecast FFDI @ hourly/5km intervals



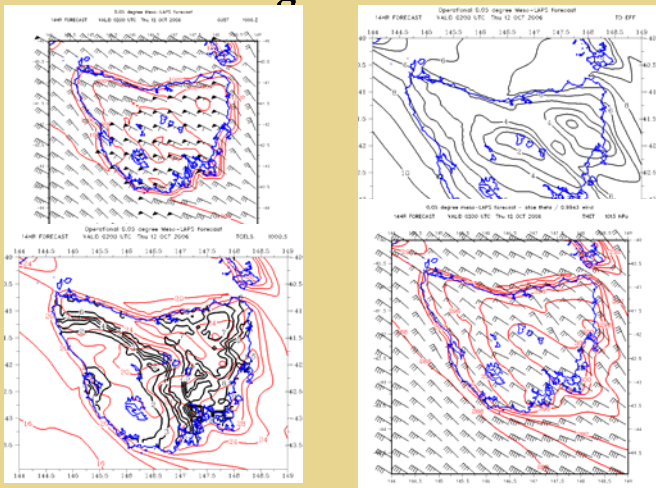
Ingredients of fdi



Tasmania – 12 October 2006

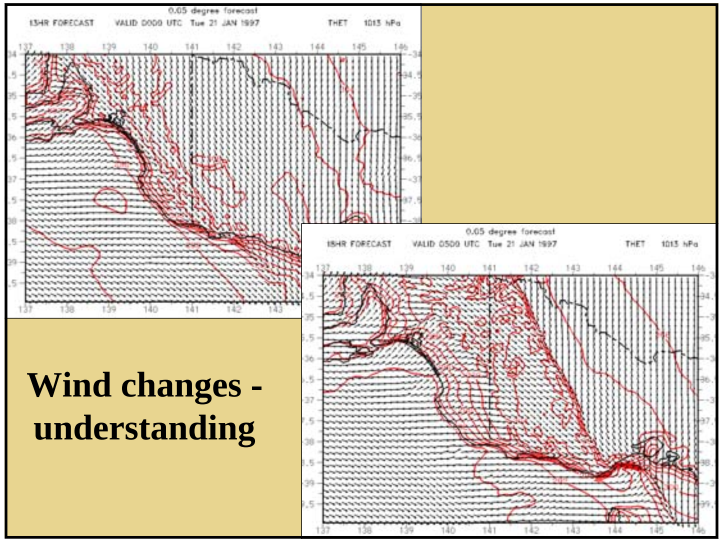


Ingredients

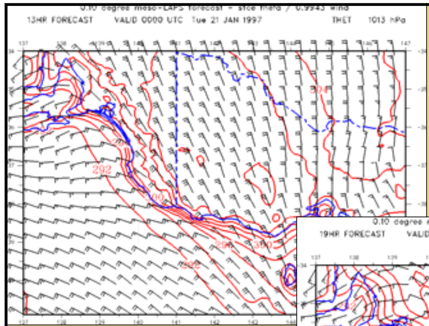


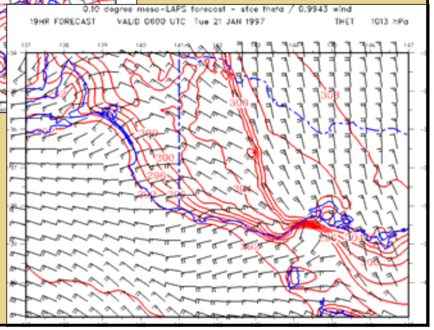
Understanding/evolution

- Cunderdin case loop.ppt
- SA Model ffdi loop.ppt

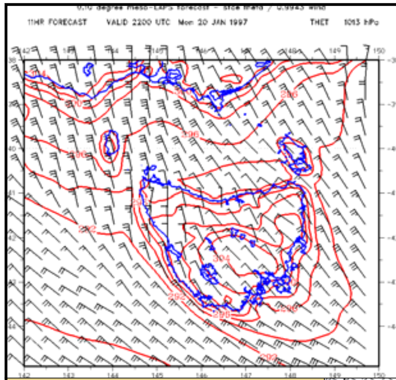


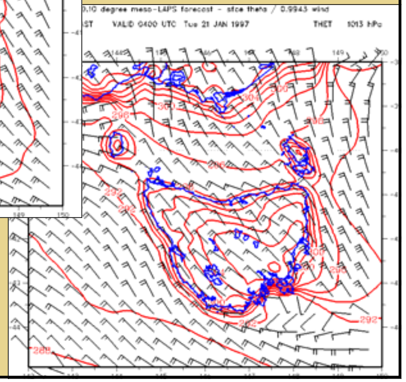
Wind changes - understanding





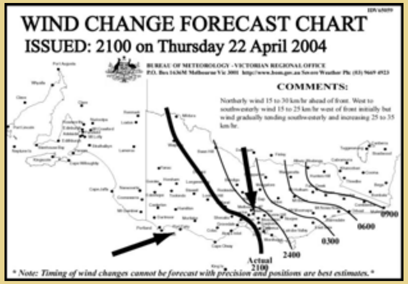
Wind changes - understanding





Wind changes - understanding

Verifying wind change timing



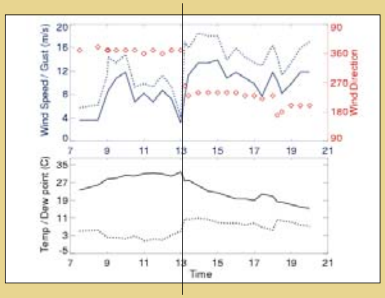
Subjective – uses regional surface analyses and station time series

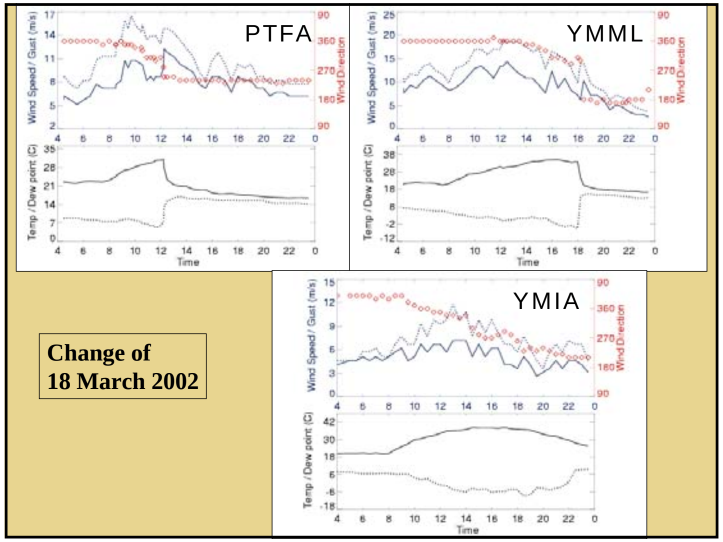
Objective verification of meso-LAPS wind changes

- **Objective timing from station data – the verification**

Melbourne Airport

Change of 11 Jan 2002





Change of
18 March 2002

Objective verification of meso-LAPS wind changes

- Objective timing from station data
  - fuzzy logic methods

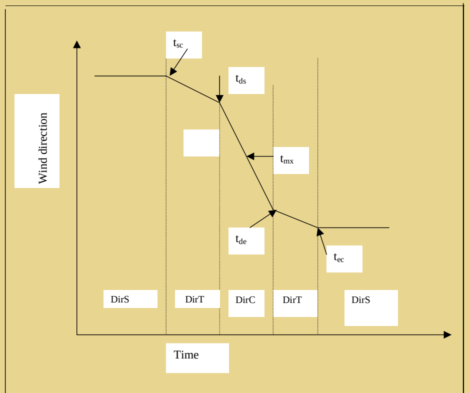
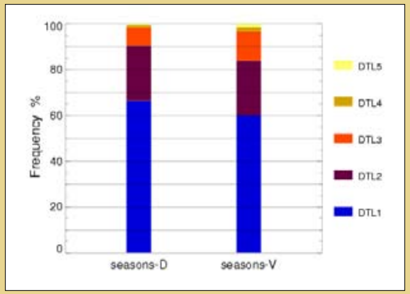


Figure 1. A schematic showing the conceptual structure of the cool change used in the objective timing decisions. t_{sc} is for wind change start time and t_{ec} is for end change time. t_{ds} and t_{de} are the time just before and after change state. t_{mx} is time when WCRI is maximum.

Timing difference level	Symbol	Description
1	DTL1	$\| t_{rfc} - t_{mx} \|$? 0.5 hr
2	DTL2	$\| t_{rfc} - t_{mx} \| > 0.5$ hr, but $\| t_{rfc} - t_{mx} \|$? 2.5 hr
3	DTL3	$\| t_{rfc} - t_{mx} \| > 2.5$ hr but $t_{sc} < t_{rfc} < t_{ec}$
4	DTL4	$t_{rfc} < t_{sc}$ or $t_{rfc} > t_{ec}$ but min[$\| t_{rfc} – t_{sc} \|, \| t_{rfc} - t_{ec} \|$] ? 2.5 hr
5	DTL5	$t_{rfc} < t_{sc}$ or $t_{rfc} > t_{ec}$ and min[$\| t_{rfc} – t_{sc} \|, \| t_{rfc} - t_{ec} \|$] > 2.5 hr

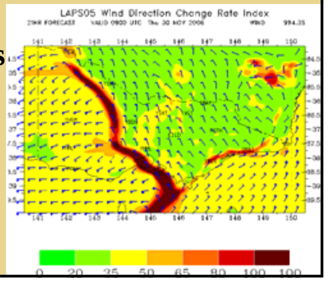


Objective verification of meso-LAPS wind changes

- Objective timing from station data
  - fuzzy logic methods
- Selection of events
  - fuzzy logic to select changes associated with major trough passage

Objective verification of meso-LAPS wind changes : the WCRI

- Objective timing from station data
  - fuzzy logic methods
- Selection of events
  - fuzzy logic to select changes associated with major trough passage
- Objective timing of modelled wind changes
  - WCRI – NSW case.ppt
  - WCRI – SA case.ppt
  - WCRI – TAS case.ppt
  - WCRI – VIC case.ppt
  - WCRI – WA case.ppt



Where with verification?

- Use objective timing for subjective forecast ("wind change days")
- Use objective timing for NWP forecasts (pressure trough changes)
- Use WCRI loop to understand what is "the change of the day"

Summary – mesoscale NWP provides:

- Richness of detail in model fields
- A conceptual model for the event of the day - tasnorth.ppt
- Objective guidance

AND in the near future:
better analysis, better models, more data
AND….
GFE!

Other projects

- SA Drying.ppt
- Seasonal/climate change studies seasonal.ppt

FIRE WEATHER – REGIONAL PERSPECTIVE: OPERATIONAL FIRE WEATHER FORECASTING

Mika Peace
Severe Weather Section
South Australian Regional Office, Bureau of Meteorology

Abstract:

Throughout the fire season, specialised teams of Severe Weather Forecasters produce Fire Weather Forecasts in the Regional Offices of the Australian Government Bureau of Meteorology.

The operational process of fire weather forecasting involves analysis of an array of numerical weather prediction models as well as monitoring a range of observations, including satellite imagery and weather station observations. Installation of Doppler radars is providing enhanced wind observations in real time.

The service is based around daily District Fire Danger Ratings, as well as point forecasts for individual fire sites. Enhanced services are provided on days of widespread Extreme Fire Danger and during campaign fires.

Strong liaison is required between the forecasters and customers of Fire Weather products, who vary from state to state, but include local fire fighting organisations and local managers of government and private land. These clients play an important role in relaying weather information from the fire ground back to the forecast operations.

Anticipated future trends in fire weather forecasting are development of graphical forecast products, complemented by greater resolution of the observation network.

Suggested reading:

See publications in ftp site

Fire Weather Forecasting An Operational Perspective

Mika Peace
Severe Weather Section
South Australian Regional Office

Operational Forecasting

- *Severe weather forecasters* (Disaster Mitigation Program)
- *Fire weather products*
- *The forecasting process*
- *Intra-state liaison with local fire agencies*
- *The future of forecasting – graphical products*

Fire Weather Forecasters

- *Severe weather sections in all States*
- *SA, VIC, TAS, NSW severe weather sections produce all fire weather products*
- *Some products produced by regional forecasting office staff in NT, QLD, WA*

Fire Danger

- *Wind speed, direction and gustiness*
- *Wind changes*
- *Temperature*
- *Dewpoint temperature (humidity)*
- *Lightning (dry strikes)*
- *Fuel state*
- *Forecast rainfall*
- *Cloud cover*
- *Stability*

Fire Forecasting Products

- *Fire Danger Ratings*
  GFDI's and FFDI's
- *Going fire forecasts*
- *Forecast outlooks*

Australian Government
Bureau of Meteorology

Fire Danger Ratings

Issued daily to public
Approximate thresholds are

Low	*FDI of 0-5*
Moderate	*FDI of 5-10*
High	*FDI of 10-20*
Very High	*FDI of 20-49*
Extreme	*FDI of 50+*

** thresholds vary between States (QLD 45+ Extreme)*
** variation between FFDI and GFDI ratings*

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Bureau of Meteorology

Grassland - GFDI's

- ***Grassland Fire Danger Index (GFDI)***
- ***CSIRO-modified McArthur Mark 4 Fire Danger Meter***
- *Input parameters T,Td (for RH), wind speed (and direction)*
- *Curing values*
  - *Updated weekly during fire season*
- *Fuel loads (standard 4.5 t/ha)*

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Bureau of Meteorology

Forestry – FFDI's

- ***Forest Fire Danger Index (FFDI)***
- ***McArthur Mark 5 Forest Fire Danger Meter***
- *Input parameters T,Td (for RH), wind speed and direction*
- *KBDI or Mount SDI*
  - *(long term or heavy fuel dryness)*
- *Drought factor*
  - *(short term or fine fuel drying)*

Australian Government
Bureau of Meteorology

4 day outlooks

- *Synoptic charts and text discussion of expected fire danger for the next 4 days*
- *Often combined with a teleconference briefing to fire agencies*

- *Planning for an upcoming bad fire day*
- *Used extensively during the prescribed burn season (northern and southern Australia)*

Australian Government
Bureau of Meteorology

Going Fire Forecasts

- *12 hour forecasts*
- *4 day forecasts*

- *Prescribed burns*
- *Going fires*
- *Used in campaign fires*

- *Detailed forecast for fire site*
- *Observations from the site*
- *PAWS*

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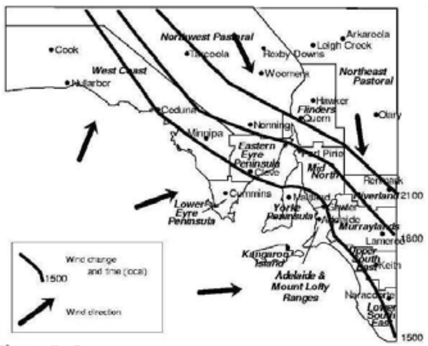
Bureau of Meteorology

Wind Change Maps



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The forecasting process -NWP

- *NWP guidance from 8 different models*
- *New model runs every 6-12 hours*
- *High resolution winds, pressure temperature, moisture through a depth of the atmosphere*
- *Variation in model skill and resolution*
- *Ground-truth NWP output against observations in real time*

Australian Government
Bureau of Meteorology

The forecast process - Observations

- *Automatic Weather Stations and synoptic observations*
- *Satellite imagery*
- *GPATs*
- *Doppler and standard radar*
- *MSLP and streamline chart analysis*
- *Balloon (sonde) flights*

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Western Australia

- Two fire seasons summer -autumn in SW land division, Pilbara dry season
- Tend towards district rating rather than point locations (verification)
- Prescribed burns - autumn busy (smoke over Perth)
- Detailed web pages for registered users
- Meteorologist position within Fire Management Services Branch of DEC

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South Australia

- Forestry forecasts (Flinders, Mount Lofty Ranges and Lower South East
- FDL for Electranet (Ash Wednesday)
- Out-posting to State Emergency Centre
- BoM issues TFB's on behalf of CFS
- Training for CFS/DEH (including PAWS)

Australian Government
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Victoria

- Forecasters provide training to CFA
- Fire weather forecasters exchange with USA during Alpine fires 2006-2007 fire season
- Australian forecasters in the US experienced out-posting to the fire ground, working alongside fire behaviour specialists

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Tasmania

- Moorland FDI for areas of the State with buttongrass
- Briefings for fire agencies ahead of bad fire weather days
- Autumn can be the busiest time – forestry prescribed burns and smoke dispersion – phone liaison

Australian Government
Bureau of Meteorology

New South Wales

- Rural Fire Service Control Centre at Homebush activates during extreme fire conditions
- Forecaster out-posted consultation/ communication role - good for media liaison
- During campaign fires forecaster out-posted to fire ground Incident Management Team
- Graphical fire danger 4-day outlooks (model-generated)

Australian Government
Bureau of Meteorology

Queensland

- Tropical fire season Aug - monsoon onset (Nov-Feb)
- Fire season in the south August -Sept- onset of thunderstorm season (Nov-Dec)
- Recent drought years have produced extended fire seasons, also short term lack of rainfall = rapid drying and rapidly changing fire risk
- SE QLD high risk – fire prone, population growth, substantial forestry
- No four day outlooks, weekly outlooks widely used - model forecasts and MJO (produces rainfall over QLD)

Australian Government
Bureau of Meteorology

Northern Territory

- Fire used actively for land management
- Burn at start of dry – reduced risk (end of wet timing and burn season)
- 4 day fire forecast outlook
- Darwin/Daly area GFDI threshold 40 (high fuel loads)

Australian Government
Bureau of Meteorology

The future of fire forecasts Graphical Products

- GFE Graphical Forecast Editor
- 2008/2009
- Automatically generated products
- National consistency
- Incorporated with GIS data formats

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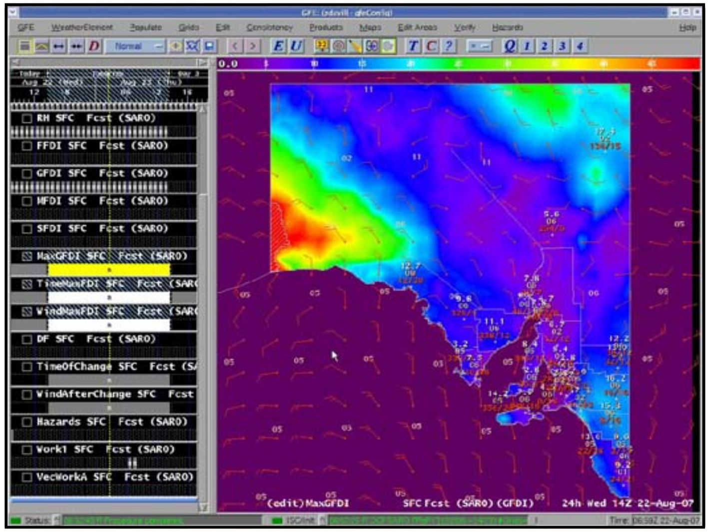


Summary

- Fire weather products
- The forecasting process
- State liaison with local fire agencies
- The future of forecasting – graphical products
- Thankyou … any questions?

Australian Government
Bureau of Meteorology

FUEL MOISTURE

Stuart Matthews
Bushfire Research Group
Ensis - Forest Biosecurity and Protection, CSIRO

Abstract:

During the past 10 years significant advances have been made in the understanding and modelling of fuel moisture. This lecture will review the experimental and model development work that has gone into the production of new models. Topics to be covered include:

- Approaches to modelling fuel moisture for research and operational use: empirical vs process-based models
- Field research and model testing
- A review of empirical models and notes on their adaptation to new fuel types
- A review of physical research leading to the development of process-based models
- Process-based models for fuel moisture in fine and coarse fuels
- Application of fuel moisture models for predicting fire spread: tactics and caveats
- New fuel moisture models for use with Project Vesta fire behaviour models

This lecture will give participants an understanding of the development of fuel moisture models, their strengths and weaknesses, and the challenges of applying models in operational situations.

Suggested reading:

Beck, J.A., 1995, Equations for the forest fire behaviour tables for Western Australia, CALMScience, 1, 325-348.

Beck, J.A. and Trevitt, A.C.F., 1989, Forecasting diurnal variations in meteorological parameters for predicting fire behaviour. Canadian Journal of Forest Research, 19, 791-797.

Catchpole, E.A., Catchpole, W.R., Viney, N.R., McCaw, W.L. and Marsden-Smedley, J.B., 2001, Estimating Fuel Response Time and Predicting Fuel Moisture Content From Field Data. International Journal of Wildland Fire, 10, 215-222.

King, A.R. and Linton, M., 1963b, Report on moisture variation in forest fuels: equilibirum moisture content. CSIRO Div. Phys. Chem. Rep., Melbourne, Australia, 9pp.

McArthur, A.G., 1962, Control burning in Eucalypt forests, Commonw. Aust. For. And Timber Bur. Leaflet Number 80, Canberra, ACT, 31pp.

McArthur, A.G., 1967,Fire Behaviour in Eucalypt forests, Commonw. Aust. For. And Timber Bur. Leaflet Number 107, Canberra, ACT, 25pp.

Marsden-Smedley, J.B., and Catchpole, W.R. 2001. Fire Modelling in Tasmanian Buttongrass Moorlands: III Dead Fuel Moisture. International Journal of Wildland Fire 10: 241-253.

Matthews, S. 2006, A process-based model of fine fuel moisture. International Journal of Wildland Fire. 15: 155-168.

Matthews, S. 2006, Course notes for 'Moisture content models – a review', 4th Short Course in Fire Behaviour Modelling, Figuera da Foz, Portugal. [Included on this CD]

Matthews, S., McCaw, L., Neal, J., and Smith, R., 2006 Testing a process-based fine fuel moisture model in two forest types, Canadian Journal of Forest Research, In press.

Nelson, R.M. jnr., 1984, A method for describing equilibrium moisture content of forest fuels. Canadian Journal of Forest Research, 14: 597-600.

Nelson, R.M., 1991, A model of diurnal moisture change in dead forest fuels, 11th conference on fire and forest meteorology, Missoula, MT, 109-116.

Nelson, R.M.., 2000, Prediction of diurnal change in 10-h fuel stick moisture content. Canadian Journal of Forest Research, 30, 1071-1087.

Ogee, J. and Brunet, Y., 2002, A forest floor model for heat and moisture including a litter layer. Journal of Hydrology 255, 212-233.

Rothermel, R.C., Wilson, R.A. Jr., Morris, G.A., and Sackett, S.S. 1986. Modeling moisture content of fine dead wildland fuels: input to the BEHAVE fire prediction system. USDA For. Ser. Res. Pap. INT-359.

Trevitt, A.C.F. 1991. Weather parameters and fuel moisture content: standards for fire model inputs. In Proceedings of Conference on Bushfire Modelling and Fire Danger Rating Systems, 11-12 July 1991, Yarralumla, ACT, Australia. Edited by N.P. Cheney and A.M. Gill. CSIRO Division of Forestry, Yarralumla. pp. 157-166.

Van Wagner, C.E., 1979, A laboratory study of weather effects on the drying rate of jack pine litter. Canadian Journal of Forest Research, 9, 267-275.

Van Wagner, C.E., 1987, Development and structure of the Canadian Forest Fire Weather Index System. Canadian Forest Service Technical Report No. 35, 37pp.

Viney, N.R., 1991, A review of fine fuel moisture modelling. International Journal of Wildland Fire, 1, 215-234.

Viney, N.R., and Hatton, T.J. 1989. Assessment of existing fine fuel moisture models applied to Eucalyptus litter. Australian Forestry 52: 82-93.

Wittich, K.P., 2005, A single-layer litter-moisture model for estimating forest-fire danger. Meteorologische Zeitschrift, 14, 157-164.

PROGRAM A

FUEL MOISTURE MODELLING

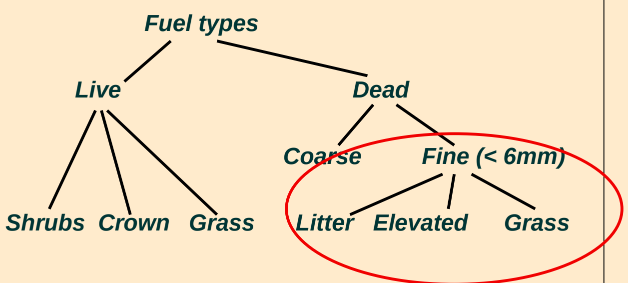
Stuart Matthews
Ensis, Forest Biosecurity and Protection, Bushfire Research

THE JOINT FORCES OF CSIRO & SCION

Fuel moisture: what?

Amount of water in a fuel, expressed as a percent of oven dry weight of that fuel

Fuel moisture: what?



Fuel moisture: why?

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Modelling fuel moisture: how?

- Empirical vs Process-based
- Both underpinned by
  - field work
  - laboratory work
  - Testing/validation

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Today's topics

1. Field work
2. Empirical models
3. Process-based models
   a) Laboratory work
   b) Model development
   c) Testing
4. Models into application
   a) Project Vesta: interim model

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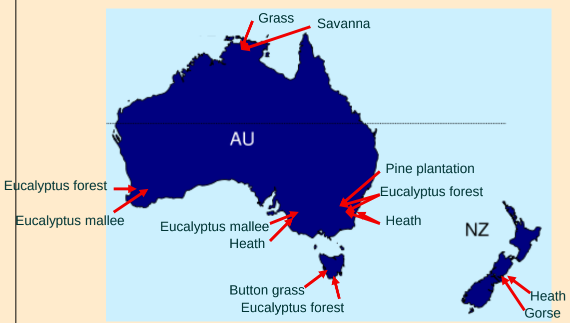
Field work



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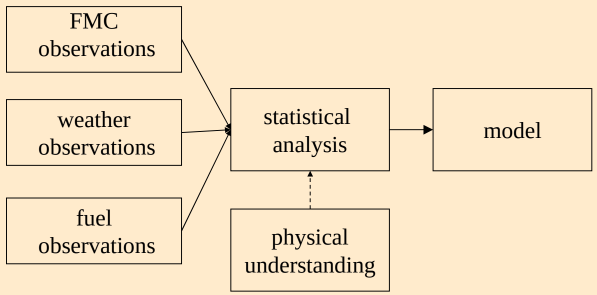
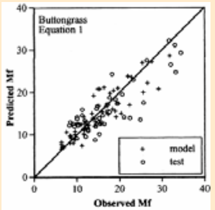
Empirical models



Empirical models

Button grass (Marsden-Smedley and Catchpole)

$$FMC = e^{1.66+0.0214RH-0.0292T_{dew}}$$



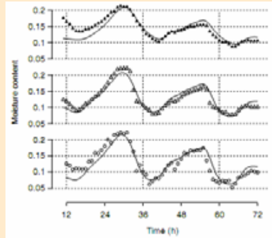
Empirical models

Catchpole et al.

$$\frac{dm}{dt} = \frac{m_e - m}{\tau}$$

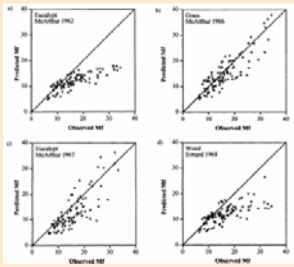
$$m_{t+dt} = f_1(m_t, m_e, \tau)$$

$$m_e = f_2(T, RH)$$

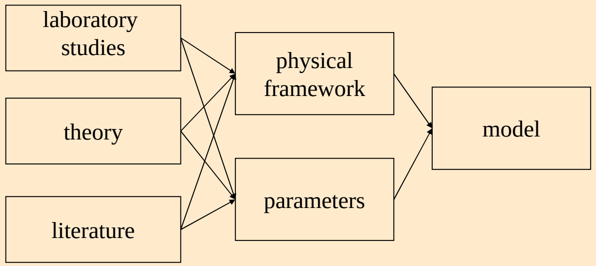


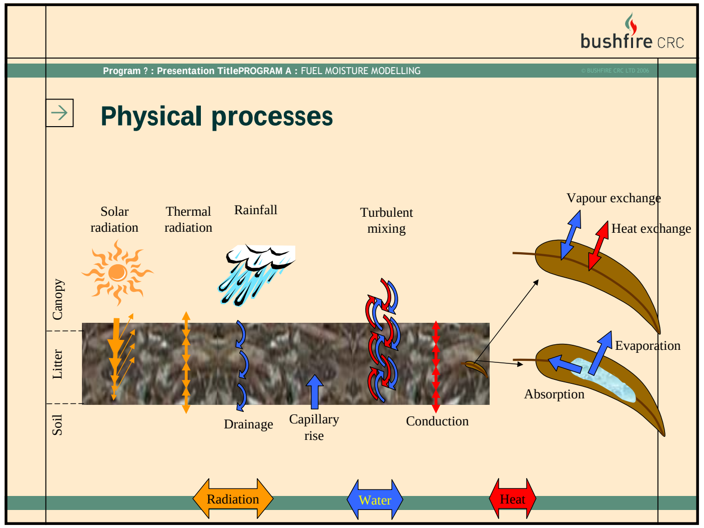
Empirical models

Assessment of existing models in new fuel types



Process based models

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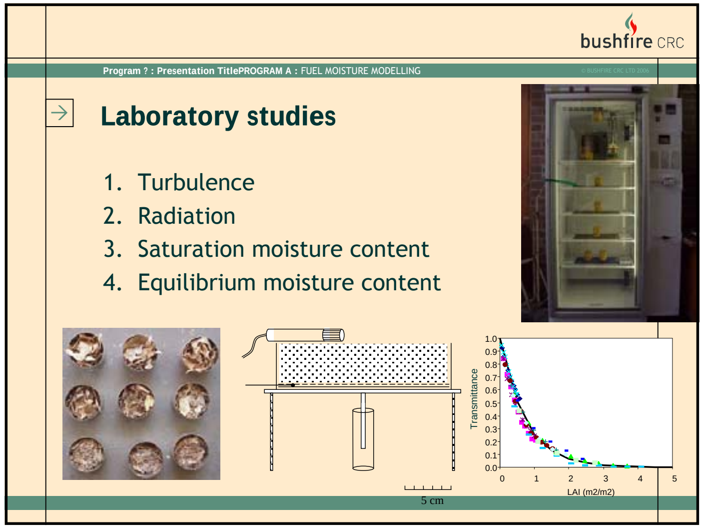
Program ? : Presentation TitlePROGRAM A : FUEL MOISTURE MODELLING
Physical processes
Solar radiation
Thermal radiation
Rainfall
Turbulent mixing
Vapour exchange
Heat exchange
Canopy
Litter
Soil
Evaporation
Absorption
Drainage
Capillary rise
Conduction
Radiation
Water
Heat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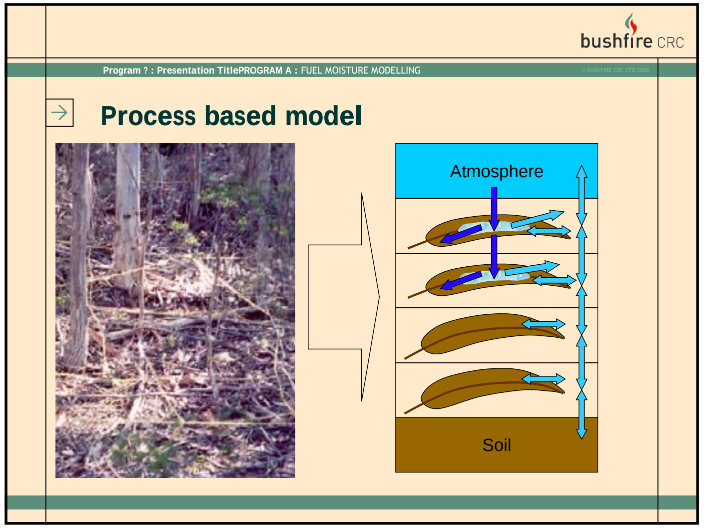
Laboratory studies
1. Turbulence
2. Radiation
3. Saturation moisture content
4. Equilibrium moisture content
5 cm
Transmittance
LAI (m2/m2)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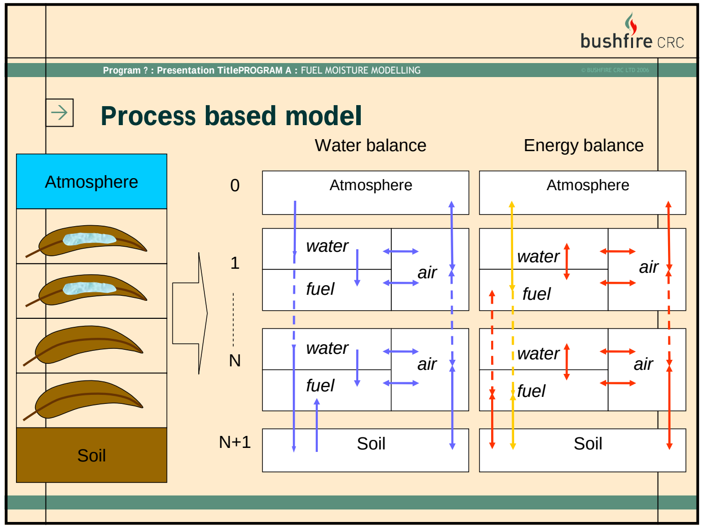
Process based model
Atmosphere
Soil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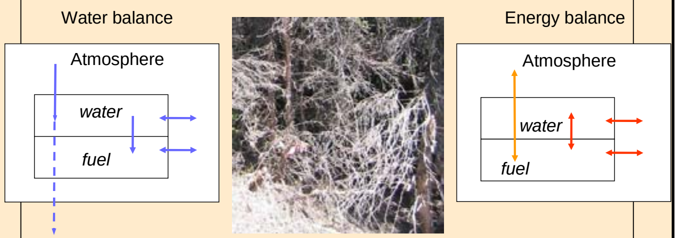
Process based model
Water balance
Energy balance
Atmosphere
Soil
0
1
N
N+1
Atmosphere
water
fuel
air
Soil

Process based model



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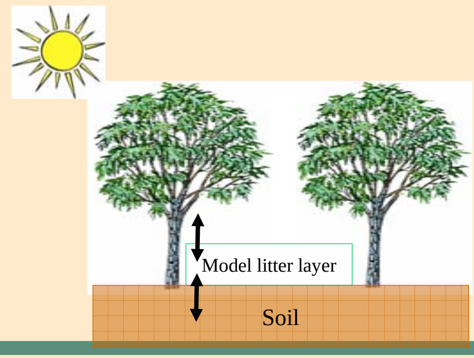
Boundary conditions



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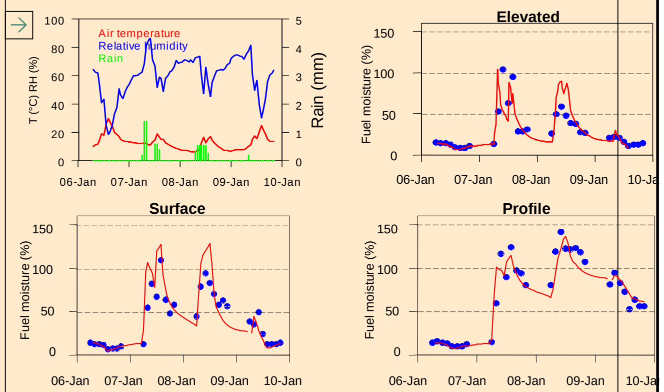

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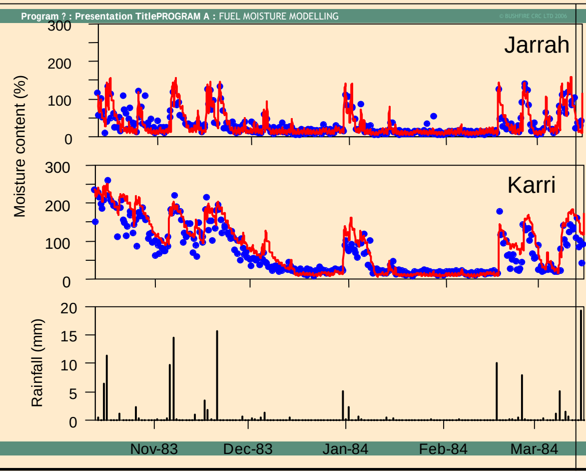

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Also…

- Testing with heath and gorse fuels
  - Project FuSE
  - CRC students
- Wittich single-layer model
- Nelson hazard rod model

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Applying models

1. Empirical models

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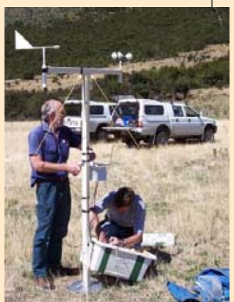
Applying models

2. Process-based models



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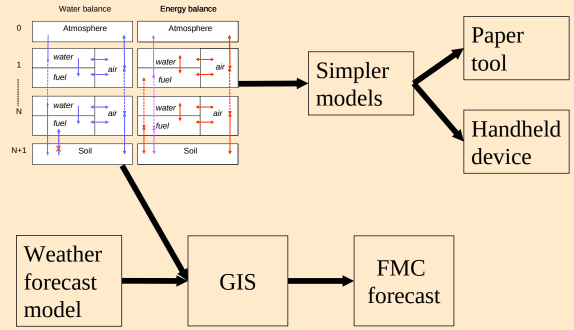
Applying models



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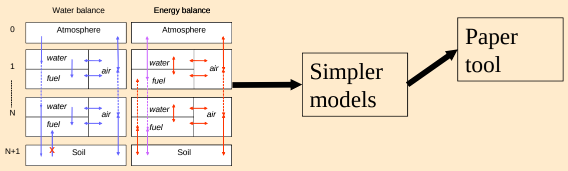
Project Vesta: interim model



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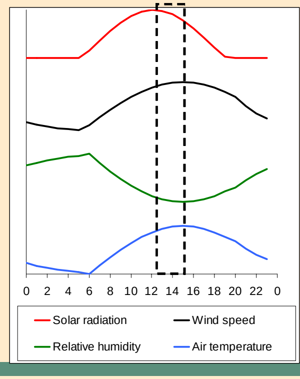
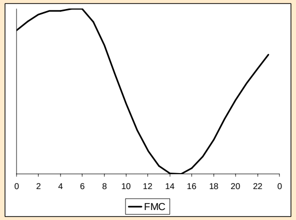
Project Vesta: interim model





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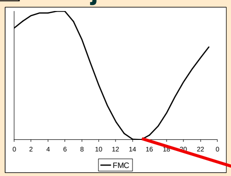
Project Vesta: interim model



	Air temperature (°C)			
Relative Humidity	10	20	30	40
5	3	3	3	3
10	4.5	4	4	3.5
15	5.5	5.5	5	4.5
20	6.5	6.5	6	5.5
25	7.5	7	6.5	6.5
30	8.5	8	7.5	7.0
35	9.5	9	8.5	8.0
40	10	9.5	9	8.5
45	11	10	10	9.5
50	11.5	11	10.5	10.0
55	12.5	12	11.5	11.0
60	13	12.5	12	12.0
65	14	13.5	13	12.5
70	15	14.5	14	13.5
75	16	15	14.5	14.0
80	17	16	15.5	15.0
85	18	17	16.5	16.0
90	19	18.5	18	17.5

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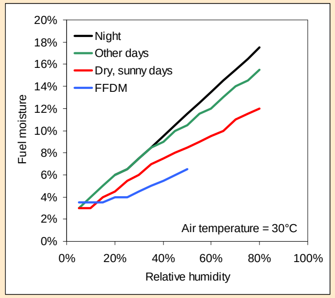
Project Vesta: interim model



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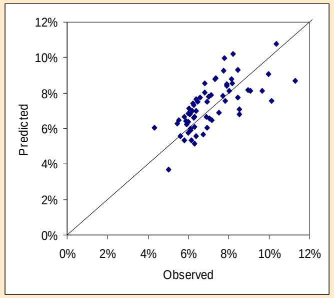
Project Vesta: interim model



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Problems still to solve

1. Micro-meteorology
2. Rain
3. Fuel moisture at night
4. Fuel moisture in the landscape

bushfire CRC

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FIRE BEHAVIOUR MODELLING – EMPIRICAL APPROACH

Wendy Anderson
School of PEMS, UNSW@ADFA
Northcott Drive, ACT

Abstract:

The lecture presents an overview of 20 year experience in designing experiments analysing data from laboratory and field experiments to produce empirical models of fire behaviour. It looks at the statistical techniques available, the pitfalls of badly designed experiments, and the consequences of the 'wrong' analysis. It also considers how to produce an empirical model, the form of the model, and the limitations of the model. Examples are drawn from fire behaviour data that the presenter has worked with in the past.

Suggested reading:

General

Harraway, J. (1997) Introductory Statistical Methods for Biological, Health and Social Sciences. University of Otago Press.

Experimental Design

Box, G.E.P., Hunter, W.G. and Hunter, J.S. (1978) An introduction to design, data analysis and model building. John Wiley & Sons, Inc.

Cox, D.R. (1992) Planning of experiments. John Wiley & Sons, Inc.

Oehlert, G.W. (2000) A first course in the design and analysis of experiments. W.H. Freeman, New York.

General regression

Draper, N.R. and H. Smith (1981). Applied Regression Analysis, Second Edition. John Wiley & Sons, Inc.

Montgomery, D.C. and E.A. Peck (1982). Introduction to Linear Regression Analysis. John Wiley & Sons.

Myers, R.H. (1989) Classical and modern regression with applications. Second Edition. PWS/Kent. Thomson Publishing.

S. Weisberg (1980). Applied Linear Regression. John Wiley & Sons, Inc.

Diagnostics

D.A. Belsley, E. Kuh, and R.E. Welsch (1980). Regression Diagnostics. John Wiley & Sons, Inc.

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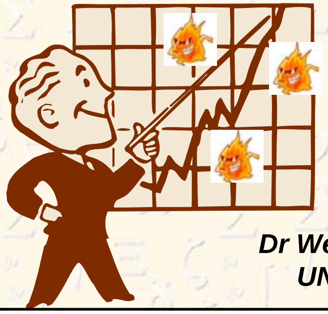
Fire Behaviour modelling – empirical approach.



Dr Wendy Anderson
UNSW@ADFA

Experimental Design

Principles of good design

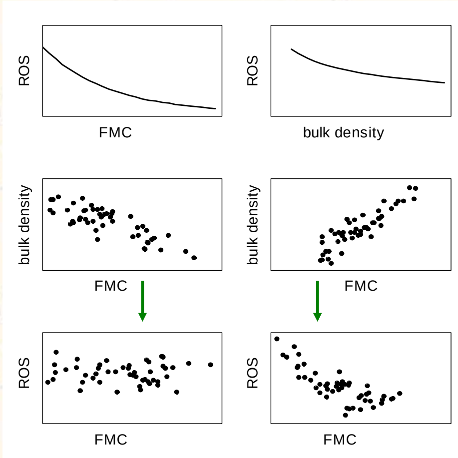
- Randomisation
- Replication
- Blocking
- Orthogonality

Poorly 'designed' experiment

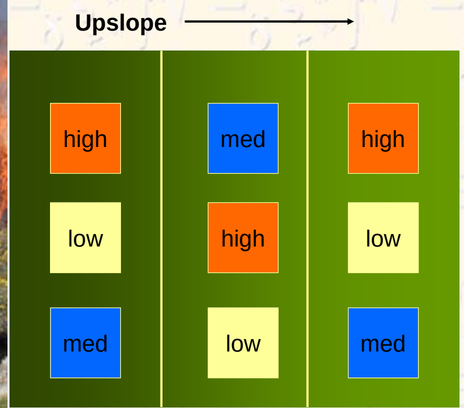
Underlying relationships

Correlated variables in the data

'Apparent' spread relationships in the data.



Orthogonality



wind speeds assigned at random to position on slope

Experimental Design - good

Project Vesta

- **2 fuel types:**
  - sparse understorey
  - moderate understorey
- **5 fuel ages:**
  - 2 - 3
  - 5 - 6
  - 8 - 9
  - 11
  - 15 - 20
- **Simultaneous fires - 120 m "instant" ignition**
- **12 replications:**
  - 2 light winds (7-10 km/h)
  - 5 moderate (12-18 km/h)
  - 5 strong (18- 25 km/h)

Conservation and Land Management

CSIRO

Data Analysis

Linear regression

- The first-order linear model or simple linear regression model

$$y = \beta_0 + \beta_1 x + \varepsilon$$

y = dependent variable
x = independent variable
β_0 = y-intercept
β_1 = slope of the line
ε = error variable

Error variable: Required conditions

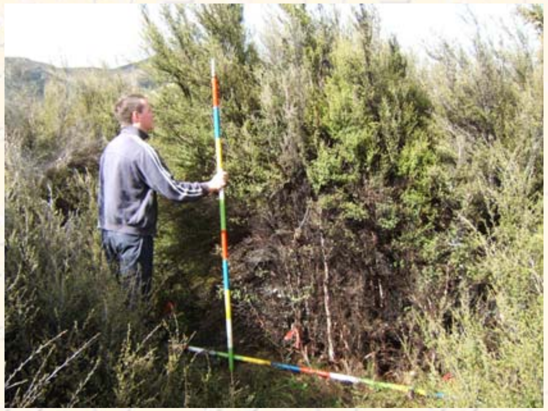
- The error ε is a critical part of the regression model.
- Three requirements involving the distribution of ε should be tested:

–The standard deviation of ε is a constant (σ_ε) for all values of x.

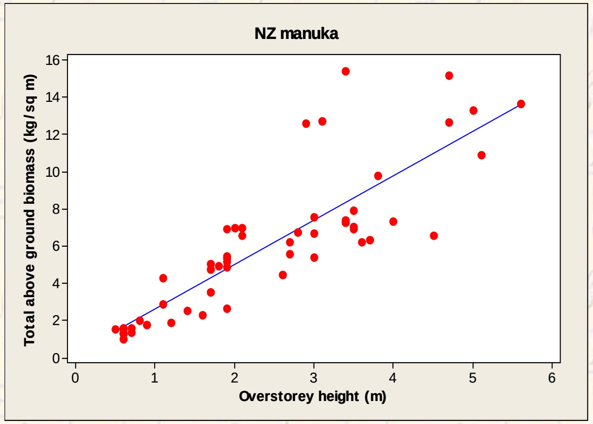
–The errors are independent.

–The probability distribution of ε is normal.

New Zealand manuka scrub (*Leptospermum sp.*)



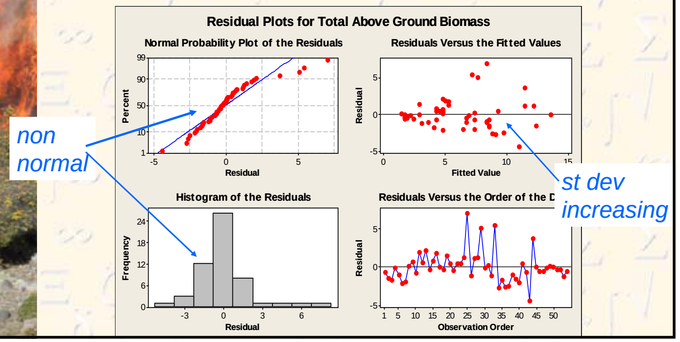
Relationship between biomass and height



Residual analysis

Examining the residuals, we can identify violations of the required conditions

Residual = Observed value – Predicted value

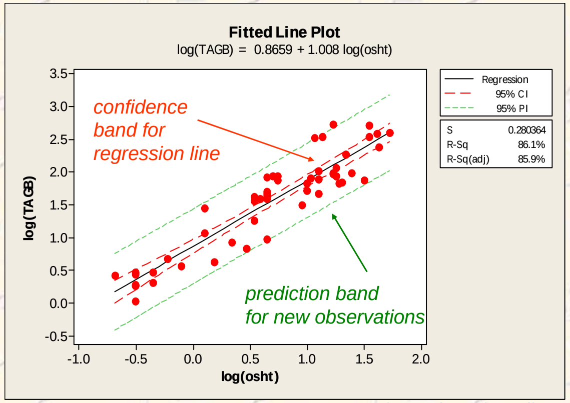


Transformations

Convenient to deal with increasing variation with mean.

transformation	W_t	
square root	$\sqrt{Y_t}$	↓
cube root	$\sqrt[3]{Y_t}$	increasing
logarithmic	$\log(Y_t)$	strength
negative reciprocal	$-1/Y_t$	↓

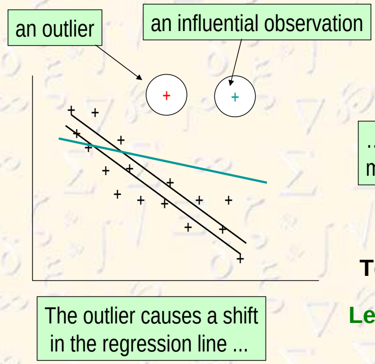
Log transformed data



transformation of predictor variable preserved linearity

Outliers

- An *outlier* is an observation that is unusually small or large.
- Several possibilities need to be investigated when an outlier is observed:
  - There was an error in recording the value.
  - The point does not belong in the sample.
  - The observation is valid.
- Identify outliers from the scatter diagram.



... but some outliers may be very influential.

Test for leverage

Leverage $H_i > 4/n$

Test for influence:

Cook's $D_i > 1$

Goodness of fit

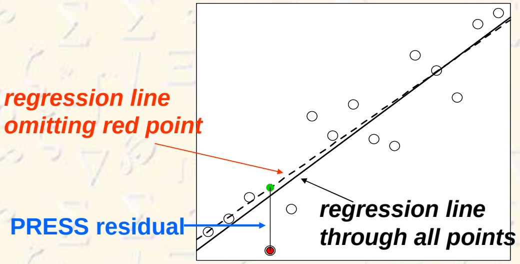
R^2 measures the proportion of the variation in *y* that is explained by the variation in *x*. It is the most used measure of goodness of fit. It is calculated from

$$R^2 = \frac{SSR}{SST} = 1 - \frac{SSE}{SST}$$

SS regression (SSR), SS error (SSE), SS total (SST)

If possible the model should be testing on a random set of observations that have been 'withheld'

If this is not possible the R^2 from the 'errors' in the **PRESS** residuals can be used as substitute.

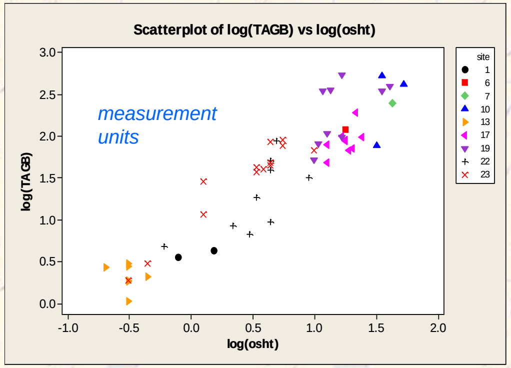


$$R^2_{PRESS} = 1 - \frac{SS_{PRESS}}{SST}$$

$R^2 = 0.836$ $R^2_{PRESS} = 0.792$

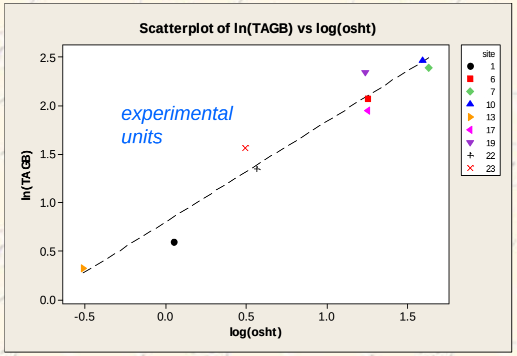
The PRESS R^2 gives us a better way of evaluating the fit of the model

Experimental and measurement units



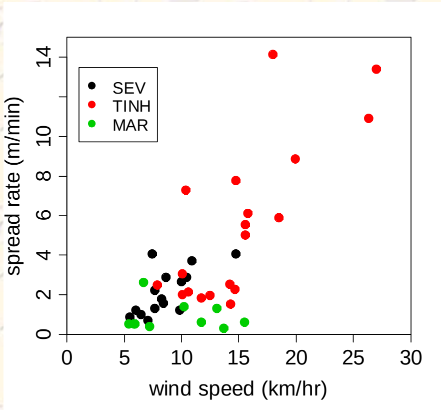
We want to predict TAGB for a site, given the average height on the site – we need to look at site averages.

Site averages



Weighted least squares with weights proportional to the inverse of the squared standard errors (σ_i^2/n_i) should be used.

Components of variance



micro-plots on 3 shrubland sites

Microplots in shrubland in Portugal

Residuals after fitting wind speed examined to see what other variables affected ROS

e.g.

$$RES = \beta_0 + \beta_1 H + S_i + \varepsilon$$

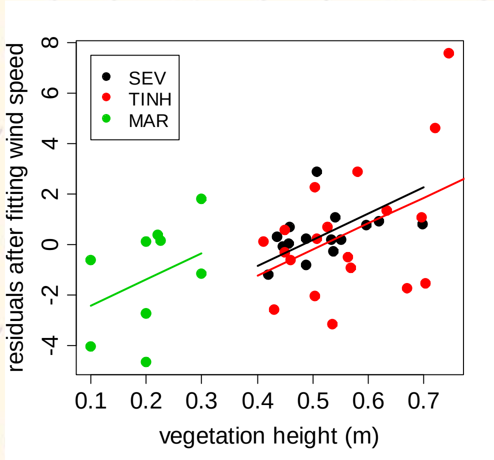
residuals — vegetation height — random site effect — within site error

ANOVA

```
Error: site
          Df  Sum Sq Mean Sq F value  Pr(>F)
height     1 23.3953 23.3953  85.838 0.06845 .
Residuals  1  0.2726  0.2726
---
Error: Within
          Df  Sum Sq Mean Sq F value   Pr(>F)
height     1  34.936  34.936  10.119 0.002835 **
Residuals 40 138.101   3.453
```

between site: just not significant

within site very significant



Multiple regression

The multiple linear regression model

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_p x_p + \varepsilon$$

y = dependent variable

x_i = independent variables – may be function of one or more variables.

e.g. X_1 = height x cover

Multicollinearity

Explanatory variables are highly correlated with each other.

(a) Coefficients are poorly determined (large standard errors)

(b) No understanding of which how each explanatory variable affects the response variable

(c) If model is used in situations where underlying correlation is different the model will predict badly.

(d) Different computer programs may give different solutions

Measuring multicollinearity

Variance inflation factor of each predictor variable

$$\mathrm{VIF}_i = \frac{1}{1 - R_i^2}$$

R_i^2 for regression of x_i on other x variables

$\mathrm{VIF}_i = 0 \Rightarrow$ no multicollinearity of ith variable

$\mathrm{VIF}_i \to \infty$ as $R_i^2 \to 1$

Generally a problem if VIF > 4

Avoiding the problem

Correlated explanatory variables should be avoided by

(i) doing stepwise regression (if one variable is in the regression the correlated variable tends not to be)

(ii) forming another variable from a sensible combination of the correlated variables,

e.g. Y = volume of timber, X_1 = DBH, X_2 = tree height

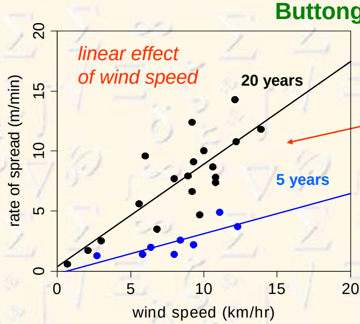
Use $X_1^2 X_2$

Selecting a model

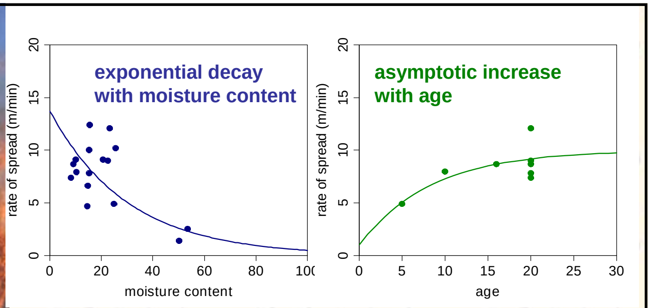
Plot graphs of response variable versus explanatory variable

- form of relationship
- transformations

Buttongrass moorland



Buttongrass moorland experimental sites



10 possible variables could be considered:
wind speed, FMC, age, cover, total biomass, bulk density, percent dead etc.

Correlations among some of these variables are high, e.g, cor(bulk density,height) = 0.86

Selecting variables

Increasing the number of variables in a regression will always increase the R^2 value, but possibly not sufficiently to be worthwhile. The aim to use as few variables as possible.

We consider:

- Best subsets regression
- Stepwise regression

Best subsets regression

R^2 does not take into account the extra parameters added to the model. Define **adjusted R^2** as

$$\bar{R}^2 = 1 - (1 - R^2)\frac{(n-1)}{(n-k-1)}$$

(penalises R^2 for increased number of parameters)

We can test the improvement in model with $\bar{R}^2$

Alternatives:

Minimize **Standard error of estimate s**

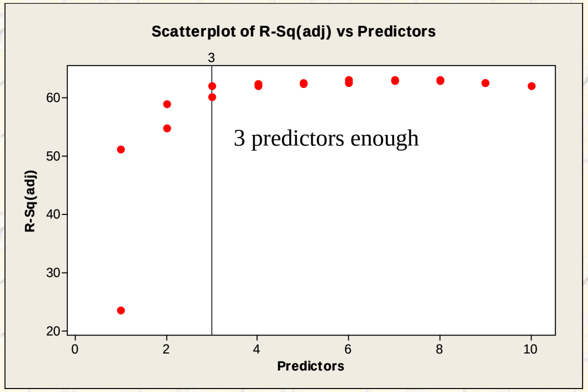
Mallow's *Cp* statistic
Chose the model with least parameters *p* such that *Cp* ~ *p*+1

Best subsets

Ignoring form of relationships for simplicity

Log(ROS)

Vars	R-Sq	R-Sq(adj)	Mallows C-p	S	wind	FMC	age	cover	bulktot	bulkdead	ht	tot	pdead	iglngth
1	51.7	51.1	27.9	0.71537	X									
1	24.5	23.6	93.2	0.89436		X								
2	59.8	58.9	10.4	0.65604	X	X								
2	55.7	54.7	20.3	0.68886	X		X							
3	63.4	62.1	3.9	0.62995	X	X	X							
3	61.4	60.1	8.6	0.64668	X	X							X	
4	64.1	62.4	4.2	0.62731	X	X	X	X						
4	63.7	62.0	5.1	0.63066	X	X	X							X
5	64.7	62.6	4.8	0.62582	X	X	X	X		X				
5	64.5	62.4	5.2	0.62745	X	X	X	X					X	
6	65.5	63.1	4.7	0.62162	X	X	X	X	X	X				
6	64.9	62.5	6.1	0.62703	X	X	X	X		X				X
7	65.9	63.1	5.8	0.62202	X	X	X	X	X	X				X
7	65.8	62.9	6.1	0.62314	X	X	X	X	X	X			X	
8	66.2	63.0	7.1	0.62297	X	X	X	X	X	X			X	X
8	66.1	62.8	7.4	0.62415	X	X	X	X	X	X	X			X
9	66.2	62.5	9.1	0.62671	X	X	X	X	X	X		X	X	X
9	66.2	62.5	9.1	0.62676	X	X	X	X	X	X	X		X	X
10	66.2	62.1	11.0	0.63026	X	X	X	X	X	X	X	X	X	X



Stepwise regression

1. Stepwise forward regression
2. Stepwise backward regression
3. Stepwise forward-with-a-backward-look

Forwards:

Step 1. Pick the variable with the highest R^2.

Step 2. Keep this variable and try all pairs including this variable. Pick the pair with the highest R^2

Step 3. Keep this pair and try all triples including this pair. Pick the triple with the highest R^2 and so on. Process finishes when no additional variable is significant.

Stepwise regression for Buttongrass example

Entry and removal based on alpha (*p*-value for *t* test)

3 predictors are included in the model

```
Stepwise Regression: log(HROS) versus wind,
        FMC, ...

Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15


Response is log(HROS) on 10 predictors,
with N = 92


Step              1        2        3
Constant    -0.2295   0.4690   0.1062

wind          0.182    0.158    0.144
T-Value        9.81     8.85     8.04
P-Value       0.000    0.000    0.000

FMC                  -0.0184  -0.0179
T-Value                -4.24    -4.29
P-Value                0.000    0.000

age                              0.033
T-Value                           2.92
P-Value                          0.004
```

Logistic regression

The logistic regression model

$$\ln\left(\frac{p}{1-p}\right) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_p x_p + \varepsilon$$

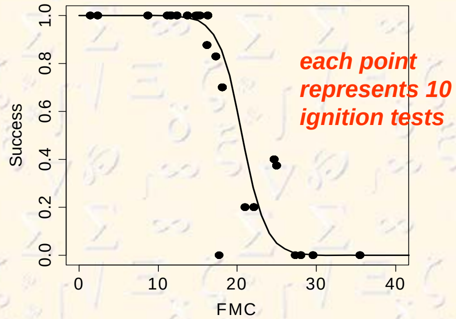
p = proportion of successes at given x_i values

x_i = independent variables – may be functions of one or more variables.

Litter ignition experiments

Model

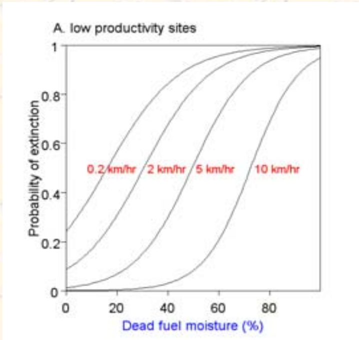
$$p = \frac{1}{1 + \exp(-[\beta_0 + \beta_1 M])}$$



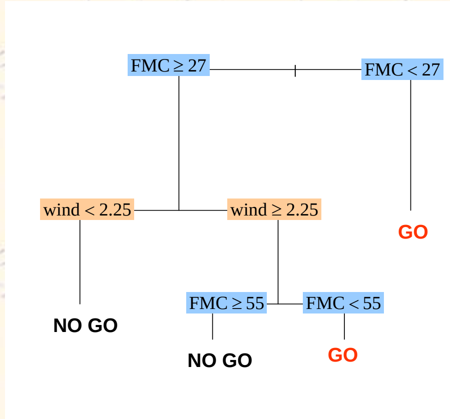
Extinction tests in moorland

Buttongrass moorland test burns

Probability of extinction depends on wind speed, moisture content, and site productivity

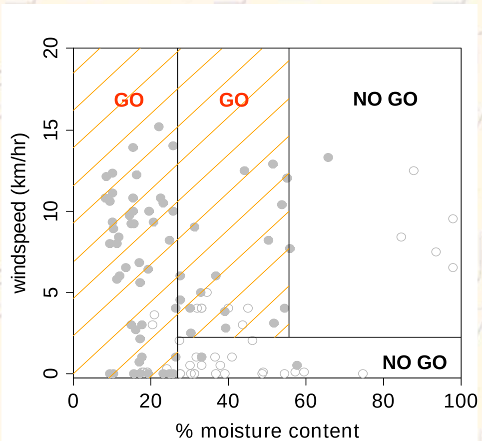


Regression trees



Low productivity site

Decision chart



Non-linear regression

$$y = f(x) + \varepsilon$$

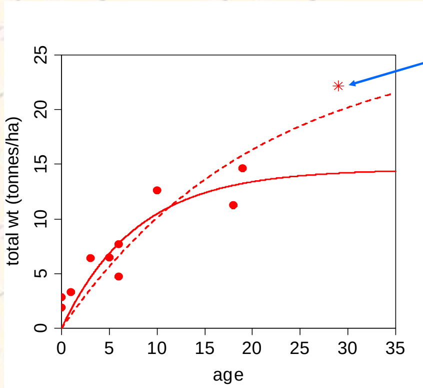
f(x) is a function of x that cannot be transformed to linearity

e.g. **Load = a(1 – exp(-b Age))**

- fitting method is iterative
- parameters need good starting values
- enough data needed to determine asymptote
- prediction bands are for large *n*

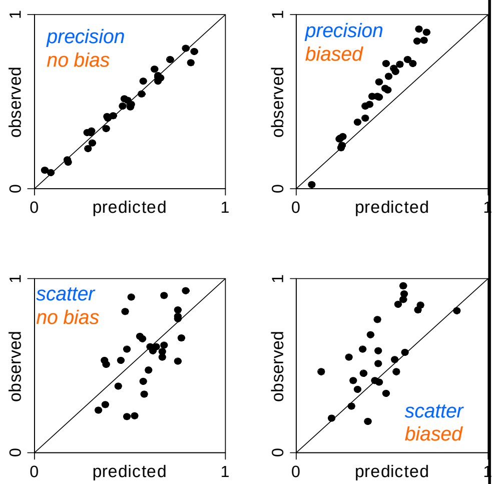
E. Amygdalina biomass accumulation (Tasmania)

Load = a (1 – exp(-b Age))



Influential observation at 30 years changes curve dramatically

Comparing observations with predictions



	precision no bias	precision bias	scatter no bias	scatter bias
Mean Error	0.00	0.13	0.01	0.17
Mean Absolute Error	0.03	0.14	0.15	0.20
Root mean square error	0.04	0.16	0.19	0.25
R^2	0.97	0.98	0.30	0.69

bias

bias and precision

precision


The End

FIRE BEHAVIOUR MODELLING – PHYSICAL APPROACH

Andrew Sullivan
Bushfire Research Group
Ensis - Forest Biosecurity and Protection, CSIRO
Yarralumla, ACT

Abstract:

Mathematical modelling of natural phenomena represents a spectrum of approaches, from the purely physical (in which the fundamental laws of nature are employed to develop the model) to the purely empirical (in which the phenomenology is described through statistical relationships). Advances in computational power in recent years have led to an increase in attempts to model the spread of bushfires across the landscape using physical models based on the fundamental understandings of the chemistry and/or physics involved in combustion and fire spread. The authors of these models tout the advantages of these models, including the ability to explore conditions beyond that possible in field experiments, but have yet to develop a model suitable for operational use. This talk will discuss what goes into a physical model of bushfire spread and outlines the advantages and disadvantages of such an approach to the modelling of the spread of bushfires.

Suggested reading:

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Physical modelling and bushfires

Or. . .
how I learned to stop worrying and love mathematics

Andrew Sullivan

Ensis Bushfire Research
Forest Biosecurity and Protection

Outline

Introduction

- Bushfire behaviour modelling has traditionally been empirical.
- Models developed from field experiments:
  - have strong operational focus;
  - are robust within the range they were developed;
  - difficult to apply elsewhere or modify.
- Restrictions on field-based experimental burning are forcing adoption of other methods of fire behaviour modelling.

Range of Modelling Approaches

There is a continuous spectrum of approaches to modelling physical phenomena:

What is physical modelling?

Physical modelling uses fundamental physical laws to build models of phenomena.

Depending on the phenomena, the laws concerned may be simple (e.g. falling under gravity in a vacuum) or highly complicated (motion of the atmosphere, quantum chemistry, genetics).

Falling under gravity

To model an object falling under the influence of gravity requires:

- identification of the physical processes involved;
- the set of governing equations to describe those processes;
- information on the initial conditions;
- information on the boundary conditions.

Falling under gravity

The governing equations in this case are those that define the relations between the object, gravity and its motion. These are Newton's Laws of Motion:

1. An object at rest will remain at rest unless acted upon by an external and unbalanced force. An object in motion will remain in motion unless acted upon by an external and unbalanced force.
2. The rate of change of momentum of a body is proportional to the resultant force acting on the body and is in the same direction.
3. All forces occur in pairs, and these two forces are equal in magnitude and opposite in direction.

Falling under gravity

The governing equations:

1. Law of Inertia:
$$\vec{a} \propto \sum_{n=1}^{\infty} \vec{F}_n$$
2. Law of Acceleration:
$$\vec{F} = m\vec{a}$$
3. Law of Reciprocal Action:
$$\sum \vec{F}_a = \sum \vec{F}_r$$

A simple 2D physical model of falling

But simply falling under gravity is no fun! (See LoM #1).
If we slightly complicate matters by incorporating:

- something to get in the way of falling straight down (such as a hill);
- resistance (friction) as the object slides down the hill;
- and drag due to air (i.e. not in a vacuum).

A simple 2D physical model of falling

But simply falling under gravity is no fun! (See LoM #1).
If we slightly complicate matters by incorporating:

- something to get in the way of falling straight down (such as a hill);
- resistance (friction) as the object slides down the hill;
- and drag due to air (i.e. not in a vacuum).

we can model tobogganing!

http://www.official-linerider.com/play.html

Physical Modelling of Bushfires

Even though the behaviour of a bushfire is very different to that of a toboggan, the method used to model a bushfire is very similar:

- Identification of the key physical processes involved.
- Formulation of the governing equations describing those processes;
- Identification of the initial conditions;
- Identification of the boundary conditions;

Primary physical processes

There are two primary physical processes involved in a bushfire:

- Release of energy from chemical reactions in the fuel; and
- Transfer of that energy to unburnt fuel.

The former involves combustion and is the domain of *chemistry*, the latter involves heat transfer and is the domain of *physics*.

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Chemistry of combustion

- The primary chemical constituent of biomass fuel is cellulose, a polymer of glucosan.
- Other major chemical components include hemicelluloses and lignin in varying amounts, depending upon the species, cell type and plant part.
- Under the application of heat, biomass fuel will undergo two distinct types of reactions: thermal degradation (or thermal decomposition) and then oxidisation of thermal degradation products.

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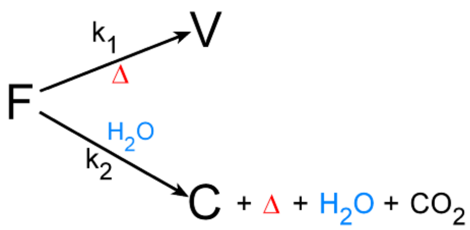
Cellulosic Thermal Degradation



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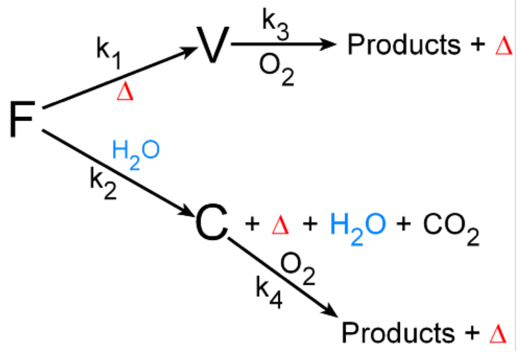
Oxidisation of Thermal Degradation Products



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Physics of Heat transfer

The processes involved in the transfer of heat in a bushfire include:

- Convection
  - Convection through a gas
  - Liquid convection
- Conduction
  - Diffusion of radicals
  - Heat conduction through a gas
  - Heat conduction through condensed materials
  - Fuel deformation
- Radiation
  - Radiation from flames
  - Radiation from burning fuel surfaces

In addition there are solid fuel transport mechanisms such as firebrand transport (i.e. spotting).

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Governing equations of physical processes

The governing equations of the physical processes of a bushfire include:

- Arrhenius law of chemical reaction rate
- Laws of Thermodynamics
- Laws of Conservation

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Arrhenius law of chemical reaction rate

$$k = Ae^{-Ea/RT}$$

where k is the reaction rate constant, A is the pre-exponential factor (related to collision theory), E_a is the activation energy of the reaction, R is the gas constant, and T is the absolute temperature of the reactants.
All reactions are highly temperature sensitive.

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Laws of Thermodynamics

The four laws are:

- Zeroth law of thermodynamics: thermodynamic equilibrium is an equivalence relation.
- First law of thermodynamics: the conservation of energy.
- Second law of thermodynamics: entropy increases over time.
- Third law of thermodynamics: absolute zero temperature

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Conservation laws

The conservation of physical quantities forms the basis of physics. In conjunction with physical laws of mass distribution, the laws of thermodynamics, Newton's laws of motion can be used to derive governing equations for the conservation of:

- **Mass:**

  Rate of accumulation of mass + Rate at which mass flows into the volume element = 0

- **Momentum:**

  Rate of increase of momentum = Inertia Force + Pressure Force + Viscous Force

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Conservation laws (cont.)

- **Energy:**

  Thermal Energy + Chemical Energy + Kinetic Energy + Energy Lost + Work Done = constant

- **Chemical species:**

  Accumulation rate of given chemical species = Convection of species out of volume + Diffusion species into volume + Production of chemical by reactions

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Issues involved in solving the governing equations

- All processes included? Turbulence, spotting, combustion, interactions?
- Correct formulations for task?
- Formulations suitable for method of solution (2D, 3D)?
- Verification of equations?
- Implementation of solution method (finite difference, finite element/finite volume)?
- Initial and boundary conditions? Fuel, wind
- Computational requirements (domain size, time step, spatial resolution, numerical stability, convergence)?
- Validation of results? Comparison against reality?

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Examples of physical models of fire behaviour

- Two major models:
  - FIRETEC, Los Alamos National Laboratory, USA;
  - Wildland Fire Dynamics Simulator (Mell 2006), National Institute of Science and Technology, USA;
- Both models are significant proprietary code run on supercomputers;
- Both utilise mesoscale meteorological models to provide atmospheric boundary conditions;
- Both models implement a raft of simplifications and assumptions in order to achieve a computationally tractable model.

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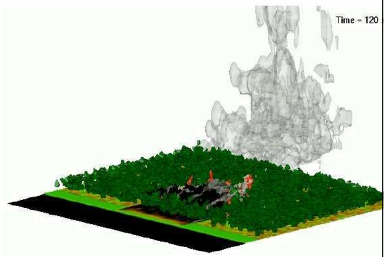
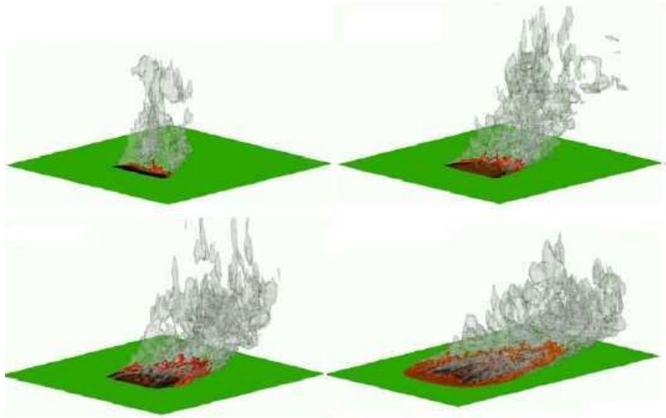
FIRETEC

- FIRETEC nested within larger scale high gradient flow solver;
- Combustion chemistry: single solid-gas phase reaction:

  $N_f + N_{O_2} \rightarrow \mathit{products} + \mathit{heat}$
- 3D solutions to equations calculated with grid resolution $\simeq 2 \times 2$ m at a time step of 0.002 seconds;
- Fire perimeters shown at isothermal = 500 K;
- "Orders of magnitude greater than realtime".

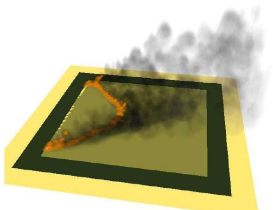


FIRETEC output

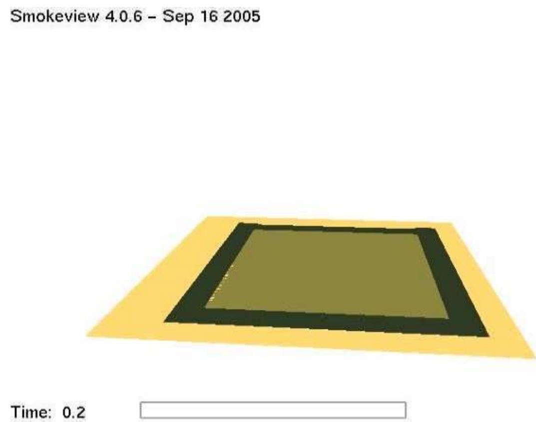


Wildland Fire Dynamics Simulator

- Solvable domain $\simeq$ 1.5 km $\times$ 1.5 km $\times$ 200 m high;
- 3D solutions to equations calculated with grid resolution $\simeq 1.6 \times 1.6$ m, vertically $1.4 \rightarrow 5.5$ m, time step unknown;
- Combustion chemistry: single solid-gas phase reaction from fuel gases generated by wood pyrolysis;
- Fire perimeters shown at isothermal = 500 K;
- 25-48 hours to compute 100 seconds of simulation.



Wildland Fire Dynamics Simulator output



In summary. . .

- The full physical modelling of bushfires in 3D is a relatively new and growing field.
- It descends from a strong heritage of computational fluid dynamics modelling—atmospheric/climate/ocean modelling.
- Fundamental laws of nature used to formulate governing equations of processes involved in bushfire.
- Computing power continues to increase over time (increased capability).
- The ability to explore conditions that are not easily studied in the field.

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But. . .

- Not all processes have rigorously established governing equations.
- Capturing the processes over the large range of scales involved in bushfires is quite difficult.
- Method of solving governing equations is just as difficult as the equations themselves.
- Necessary trade-off between detail of solution and computational capability: considerable need for assumptions and simplifications.

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But. . . (cont.)

- Solutions to governing equations require considerable computational capability.
- Information needs for initial and boundary conditions quite extensive.
- Accurate validation of results is difficult.
- The cost of running a simulation on a supercomputer may be in the same order as a field experiment.
- A purely physical model of fire spread will not be suitable for operational use.

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However. . .

- Physical modelling of natural phenomena continues to be a growth area.
- While the application to bushfires is in its infancy, the results of physical modelling are becoming more prevalent in day-to-day life.
- Perhaps the first test of a physical model is if an experienced observer can't tell it's not real. . .

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The End

Thank you

GRASSLAND FIRE BEHAVIOUR

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Abstract:

Grass is the most common fuel in Australia covering nearly 75 percent of the country landscape. Grassland fuel types range from the vast tropical savannah of northern Australia to the improved pastures of southern Australia. Although grass fuel are relatively simple compared to forest and heath shrub fuels, different species of grass of grass form a wide range of structural types which generate different fire behaviour characteristics. With known weather variables, grassland conditions – structure and degree of curing the behaviour of grassfires such has rate of spread, distance the fire will travel can be predicted. Sound understanding of the factors the influence grassfire behaviour is important for fire managers and fire fighters to use the fire behaviour prediction system to make reasonable predictions of the behaviour and spread of grassfires.

Suggested reading:

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PROGRAM A

Grass fire behaviour

Jim Gould
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Grassfire behaviour

1. fuel burns quickly: 5-10 sec
2. spread very fast: 20 km/h
3. build up very rapidly
4. very responsive to changes in wind speed and direction
5. relatively low flames: 5-8 m

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Factors affecting fire spread

1. Pasture condition
   a) Continuity (grass type, e.g. Spinifex)
   b) Condition (eaten-out, grazed, natural)
2. Fuel moisture
   a) Grass curing state
   b) Dead fuel moisture content
3. Head fire width
4. Wind speed
   a) Incorporates fire width

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Pasture condition

Natural

Undisturbed and/or very lightly grazed natural grasses (generally > 50 cm tall)

Pasture condition

Grazed

Grazed or mown pastures (generally < 10 cm tall). Common condition in SE Australia in summer

Pasture condition

Eaten-out

Very heavily grazed (generally < 3 cm tall), scattered patches of bare ground

Grass curing

1. Drying process after grass has flowered, set seed, and begun to die off
2. Mainly annual species but process complicated in perennial species
3. Prior to curing process, moisture content of grass mainly derived from green content
4. After fully cured, moisture content derived from atmospheric conditions (e.g. air temperature, relative humidity)
5. Function applies to uniformly cured pastures.
6. Curing of the landscape is spatially variable, e.g. Creeks & gullies green, ridges cured.

0% cured- will not burn

30% cured- will not burn

Photo: CFA Victoria

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Degree of grass curing

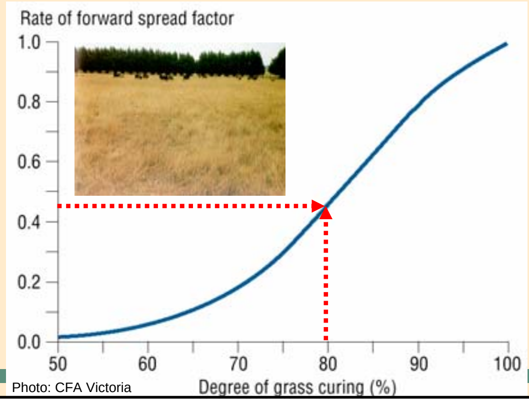

Photo: CFA Victoria

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Degree of grass curing

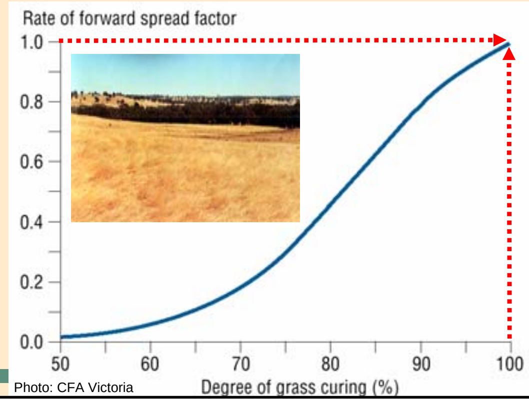

Photo: CFA Victoria

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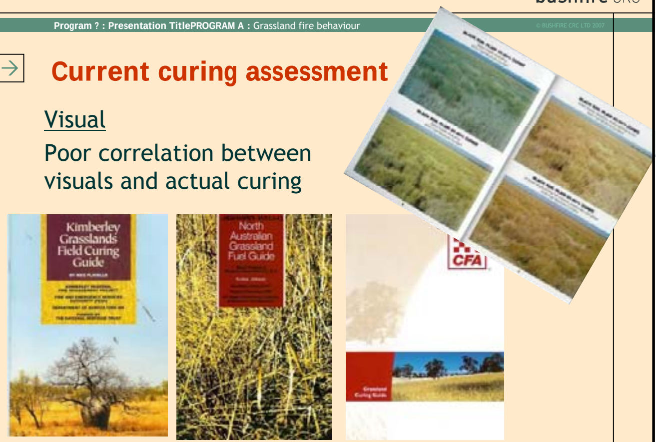
Current curing assessment

Visual

Poor correlation between visuals and actual curing



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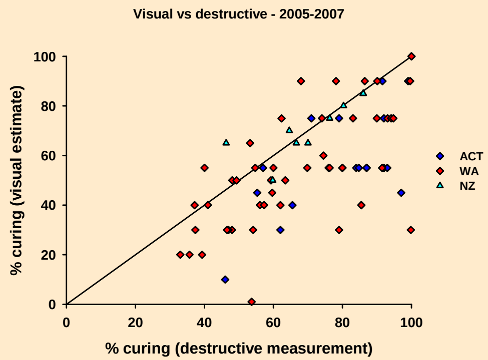
Curing assessment: Visual



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Curing assessment: Levy Rod approach

- Total number of live and dead grass touching a thin steel rod along a fixed transect
- Easier, quicker and more reliable than other techniques
- Developed and tested in ACT, NSW, NZ
- Extended to WA and Qld

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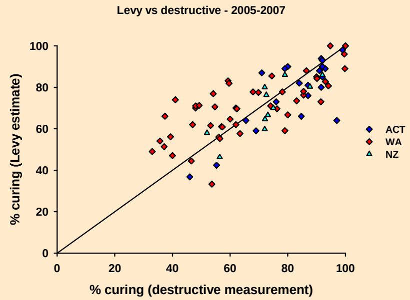
Curing assessment: Levy rod approach



More information: Anderson and Botha conference presentation: Bushfire CRC Stream Friday @ 1100am

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Grassland fire behaviour curing function

1. Function will always over-predict when curing less than uniform 100%
   a) Wetter green gullies/creeks
   b) Drier ridge tops
2. Changes in curing across large areas
3. Recent rainfall
   a) Germinate annual grasses (green under dead grass)
   b) Reshoot perennial grasses (green over dead grass)

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Grass fuel moisture content (FMC)

1. Significant factor in determining combustibility of fuel
   a) Higher FMC, lower heat yield
   b) Lower FMC, higher heat yield
2. When green, FMC > 30%
3. When fully cured, FMC dependent on atmospheric conditions

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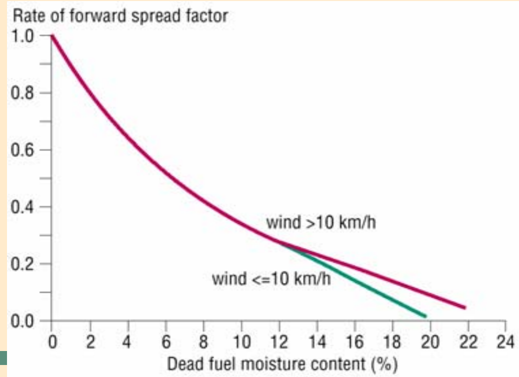
Fuel moisture content



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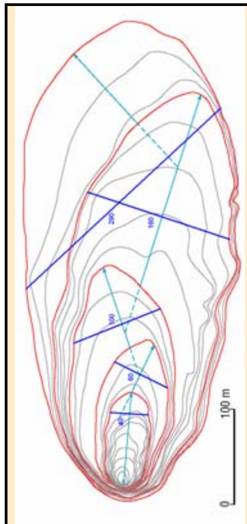
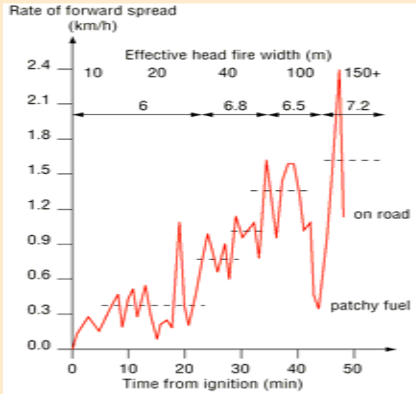
Importance of head fire width

1. Width of a fire is a critical factor that determines fire spread,
2. A fire that is restricted in width will spread at less than its potential ROS for the conditions,
3. The width required to reach the potential rate of spread depends on the wind speed.





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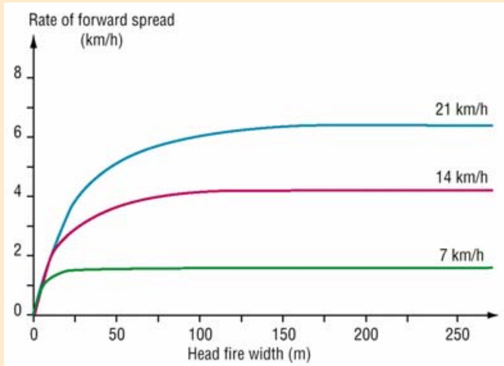
Importance of head fire width



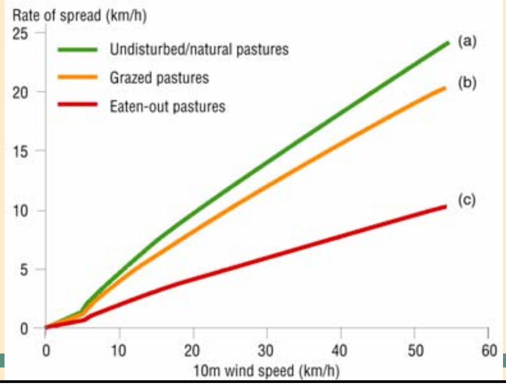
Effect of wind on ROS

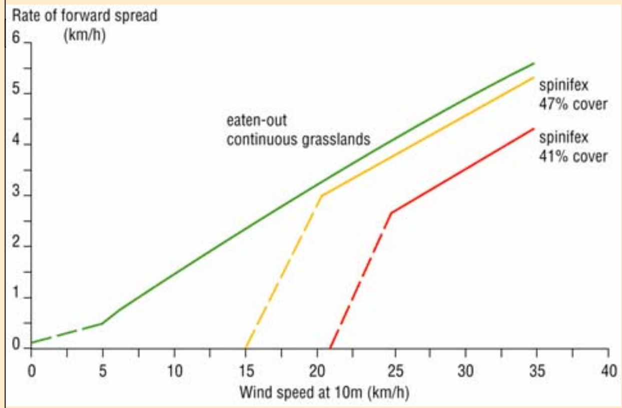
1. In the analysis of data two functions were needed to describe the effect of wind on ROS.
2. Different functions apply above and below a threshold wind speed (5 km/h).
3. In the meter we use the function for wind speeds greater than 5 km/h.
4. Use a wind speed of 5 km/h when winds are light and variable.

Threshold wind speed

1. In continuous fuels the wind speed required to move the fire as a continuous heading fire (around 5 km/h at 10 m).
2. In discontinuous fuels the wind speed required to also overcome gaps in the fuel (for spinifex 50% cover around 15 km/h at 10 m).

Wind speed





Fire spread vs. fire danger meters

Because the conditions that affect relative fire danger were found to affect rate of spread differently, we separated the calculation of fire danger from the calculation of rate of fire spread.

There is now a separate meter for the prediction of rate of spread and fire danger index.

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Grassland fire spread meters

To predict fire spread in grassland fuels there are two meters.

1. CSIRO Grassland Fire Spread Meter; and
2. CSIRO Fire Spread Meter for Northern Australia

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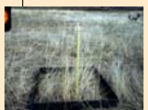

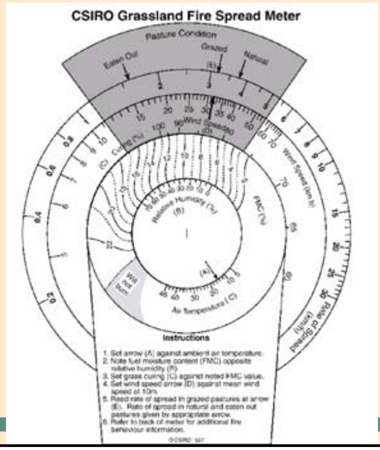

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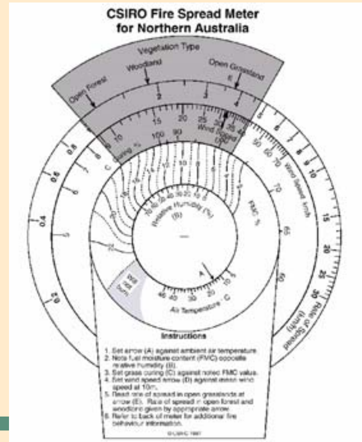

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Error in fire spread prediction

No fire spread prediction system will predict accurately 100% of the time. Why?

1. Measurement of input variables (wind speed especially) are never accurate;
2. Grassfires will always encounter a mixture of pasture types; and
3. All systems predict 'average' spread over a period.

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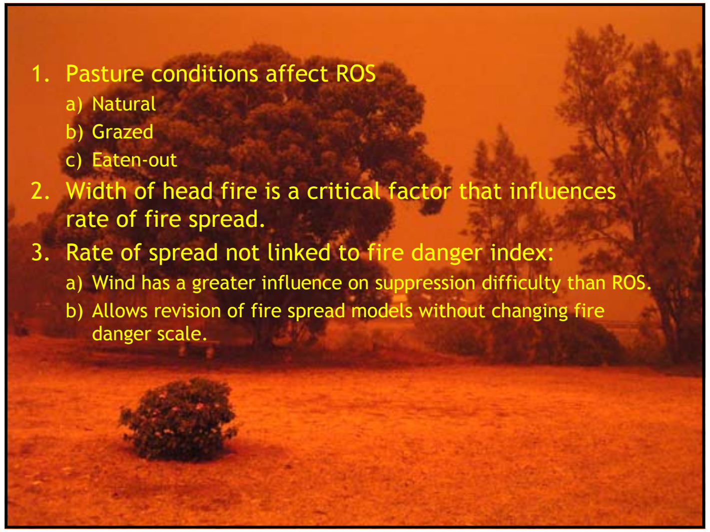
Summary

1. Width of head fire is a critical factor that influences rate of fire spread.
2. Requires a threshold wind speed of 5 km/h in continuous fuels to spread forward consistently.
3. Fuel load does not affect ROS



EUCALYPT FOREST FIRE BEHAVIOUR - PROJECT VESTA RESULTS

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Abstract:

There is a universal need for a better understanding of forest fuels and how they determine fire behaviour - particularly under severe weather conditions. This understanding is required not only to build better models to predict fire spread at a local or regional level but also to evaluate the impact of fuel reduction burning on the behaviour of wild fires under dry summer conditions. Project Vesta was an experimental study to quantify age-related changes in fuel attributes and fire behaviour in dry eucalypt forests typical of southern Australia. Over 100 experimental fires were conducted during dry summer conditions at two sites in south-western Australian eucalypt forests. Understorey fuels ranged in age since fire from 2 to 22 years. New fire behaviour models were developed that predict rate of spread and difficulty of suppression according to wind speed, fuel moisture content and variables that reflect the abundance and condition of leaf litter, understorey fuels and bark. These models predict that under conditions of high to very high fire danger the rate of spread and intensity of fire are strongly correlated with fuel age for a period of at least 15 years after fire. Experimental studies have established a clear link between visual ratings of fuel hazard and potential fire behaviour. In forests dominated by trees with fibrous bark the spotting potential and difficulty of suppression may continue to increase for considerably longer periods after fire because of the accumulation of bark on stems. For this reason prediction of fire behaviour based solely on fine fuel loading will tend to under-estimate potential fire behaviour in forests that have been unburnt for some time. The improved understanding of relationships between fuel age and potential fire behaviour in dry eucalypt forests gained from Project Vesta provides a better basis for assessing the benefits of various fuel management alternatives that

may be employed to reduce difficulty of fire suppression and protect assets from damage during high intensity wildfires. This new knowledge is important not only for planning prescribed burning programs, but also for determining, monitoring and managing suppression of wildfires.

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PROGRAM A

Project Vesta

Fire in Dry Eucalypt Forest:

fuel structure, fuel dynamics and fire behaviour

Introduction

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Project Vesta

Fire in Dry Eucalypt Forest:

fuel structure, fuel dynamics and fire behaviour

Project **Vesta** was a comprehensive research project to investigate the behaviour and spread of high-intensity bushfires in dry eucalypt forests with different fuel ages and understorey vegetation structures.

Five topics:

1. Introduction
2. Fuel assessment
3. Fire behaviour
4. Spot fire
5. Operational application

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Introduction

1. Acknowledgements
2. Background to Project Vesta
   - Aquarius
   - Annaburroo
3. Experimental design
4. Preparation
5. Experimental Measurements

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What is Project Vesta?

1. A major experimental study of fire behaviour in dry eucalypt forests of temperate southern Australia
2. Collaborative research between CSIRO, Department of Environment and Conservation, WA and other State agencies
3. Coordinated through Australasian Fire Authorities Council (AFAC)

Project Vesta supported by:

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AFAC- Australasian Fire Authorities Council

New South Wales
Rural Fire Service
State Forests
National Parks &Wildlife
NSW Fire Brigades

Queensland
Rural Fire Service
Parks and Wildlife
Dept. Primary Industry

New Zealand
Rural Fire Authority
Dept. Conservation

South Australia
Country Fire Service
National Parks

Tasmania
Fire Service
Parks and Wildlife
Forestry Tasmania

Victoria
Country Fire Authority
Dept Sustainability & Env.

Western Australia
Fire & Emergency Services Authority
Dept Environment and Conservation
WA Volunteer Bushfire Association

Project Vesta is supported by:

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Other government agencies
CSIRO Executive Office
Parks Victoria
The International Decade of Natural Disaster Reduction
Shires of Harvey, Bridgetown-Greenbushes, Mundaring, Town of Kwinana
SA Forestry

Research Grants
Hermon Slade Foundation
Forest and Wood Products Research and Development Corporation

Corporate Sponsorship
Isuzu Trucks
Australian Insurance Council

Research Support
Bureau of Meteorology
Bushfire CRC

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Suppression support

Department of Environment and Conservation
Western Australia

1. Fire Management Services Branch
2. Blackwood District
3. Wellington District
4. Perth Hills District
5. Donnelly District
6. Frankland District

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Background

1. 1982 Aquarius / Narrik fire experiments
2. 1986 Annaburroo Grassfire experiments
3. 1990 WA revision of fire spread tables
4. 1993 Scheduling prescribed burning
   - Project proposals
5. 1996 – 2001 Field experiments
6. 2001 – 2006 Analysis
7. 2007 – Final report

Aquarius / Narrik 1983

10,000 kW/m

- Flame height ≈ 40 m
- ROS ≈ 1.6 km/h

7,500 kW/m

- Flame height ≈30 m
- ROS ≈ 1.2 km/h

Aquarius- simultaneous large fires

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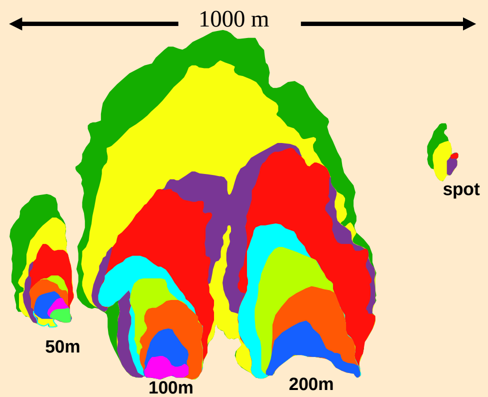

Four simultaneous experimental fires ignited in different ways

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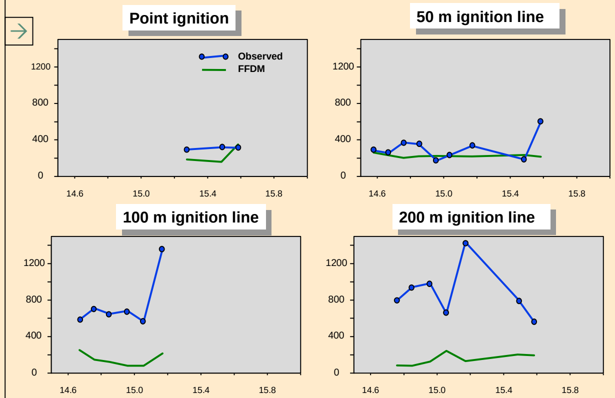

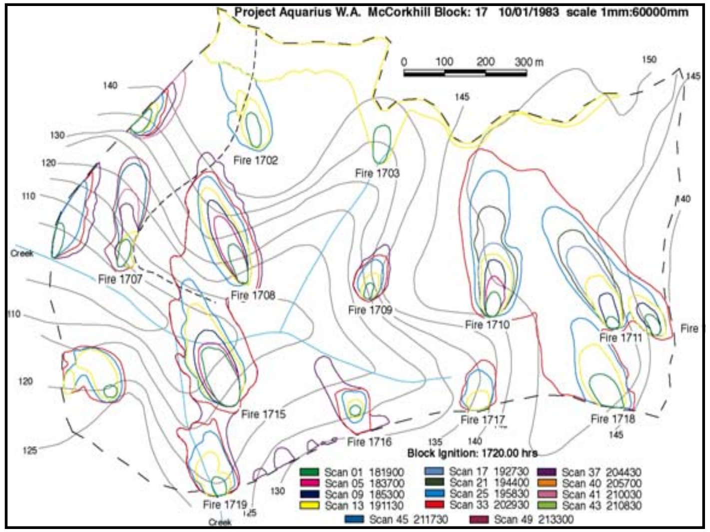

Cumulative Spread - all fires

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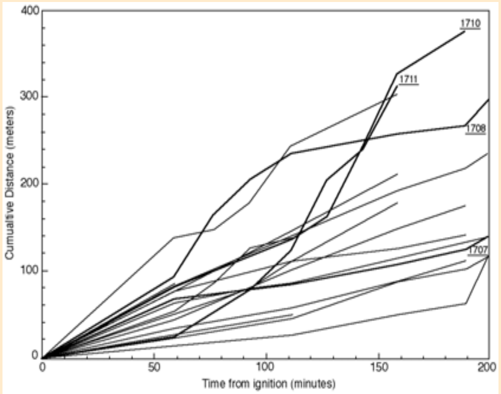

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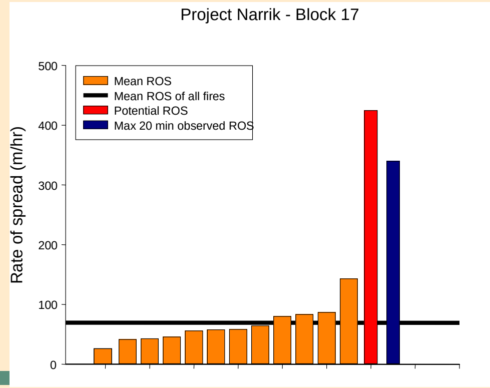
Rates of spread of individual fires



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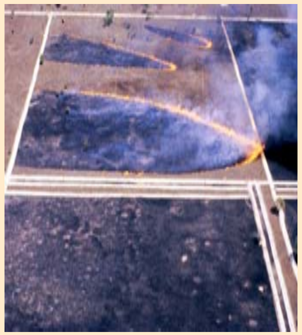
Annaburroo experiments 1986

1. ROS grassfire
   a) Wind speed
   b) Fuel moisture
   c) Ignition line length or
   d) Head fire width

2. ROS not related to
   a) fuel load
   b) Fuel fineness



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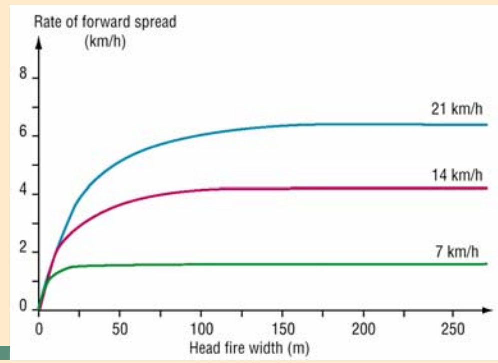
Effects of head fire width in grass fire



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Why Project Vesta?

1. Existing models under-predict by 2 times, or more in shrubby forest
2. CSIRO (1993) - rate of spread in grasslands independent of fuel load, but height is important
3. Burrows (1994) - rate of spread in 7 year-old Jarrah forest fuel independent of fuel load
4. No statistical evidence of effect of fuel load on forest fire spread

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Why Project Vesta?

1. Exponential relationship between ROS and wind speed was suspect
   a) Illogical at high winds
   b) Linear in grassfires above a threshold value
2. Needed to quantify fuel structure
3. Needed statistical evidence on the change in fire behaviour as fuels accumulate over time to justify fuel reduction burning.

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Research objectives - 1

1. Quantify changes in fire behaviour as fuels develop with age
2. A better understanding of how in-forest wind is affected by forest density and understorey
3. A new model to predict fire spread, based on better understanding of the effects of wind and fuel

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Research objectives - 2

1. Compare spotting distance and firebrand density downwind of fires in different aged fuels
2. Evaluate existing models for predicting spotting distance

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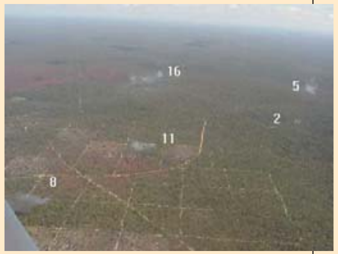
Experimental Design

1. 2 fuel types:
   a) sparse understorey
   b) moderate understorey
2. 5 fuel ages:
   a) 2 - 3
   b) 5 - 6
   c) 8 - 9
   d) 11
   e) 16 - 22
3. Simultaneous fires - 120 m "instant" ignition
4. 12 replications:
   a) 2 light winds (7-10 km/h)
   b) 5 moderate (12-18 km/h)
   c) 5 strong (18- 25 km/h)



Understorey fuel types in Jarrah forest at experimental sites in south-west WA

McCorkhill block - shrubby understorey in southern Jarrah forest unburnt for 16 years.

Dee Vee -sparse understorey in northern Jarrah forest unburnt for 19 years.

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Preliminary Tasks

1. Select areas with a range of fuel ages
2. Determine direction of consistent strong summer Wind (plot alignment)
3. Measure wind variation across the sites
4. Measure wind variation in the forest
5. Determine best exposure for anemometers
6. Measure the fuel structure (Session 2)

Plot layout at McCorkhill WA

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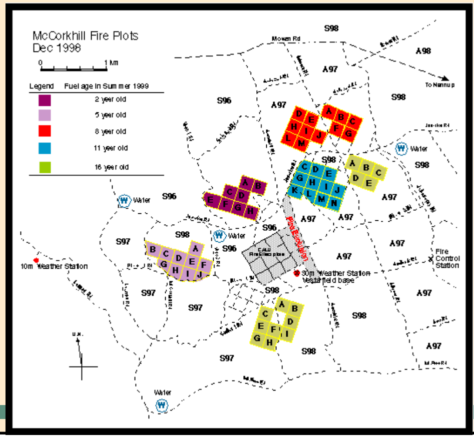
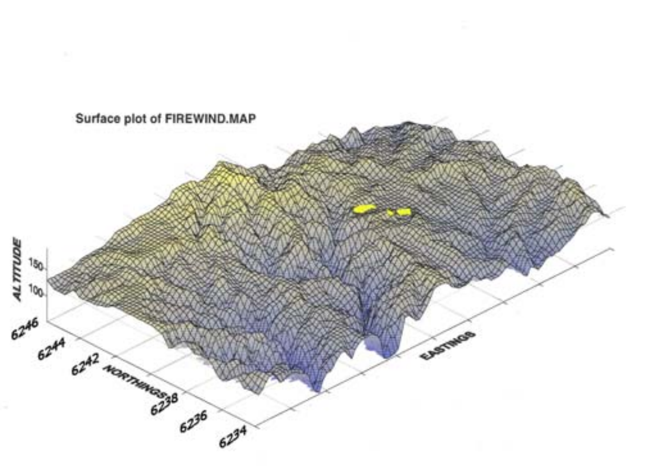
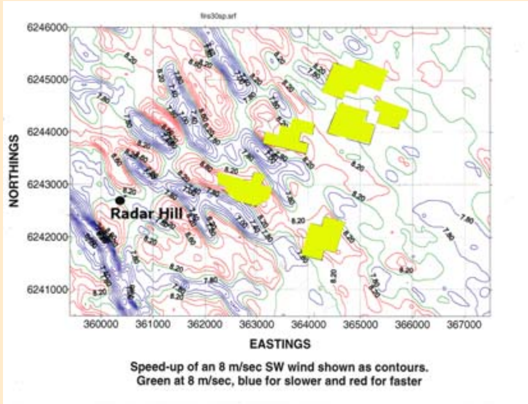


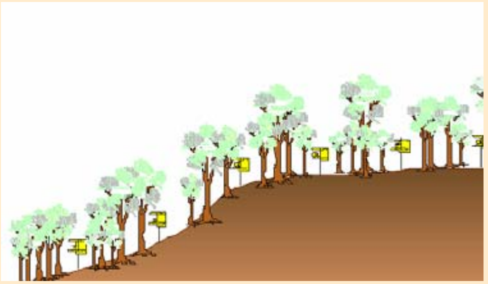
Effect of topography on wind



Effect of topography on wind



Anemometers in a hill transect to detect gust transition



Gusts have short persistence.

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Wind in the forest

1. No correlation between measurements more than 40 m apart
2. Gust small and do not travel from anemometer to fire front
3. Error due to wind measurement minimised by;
   a) several instruments,
   b) widest ignition line, and
   c) longest period of spread

Errors in estimating 5-minute wind average at a fire front as a percentage of the measured wind

No. of Anemoms	Fire Width			
	0-40m	~80m	~160m	~300m
1	±37%	±32%	±29%	±27%
2	±32%	±26%	±23%	±21%
4	±29%	±23%	±20%	±17%
8	±27%	±21%	±17%	±13%

Above canopy wind speed

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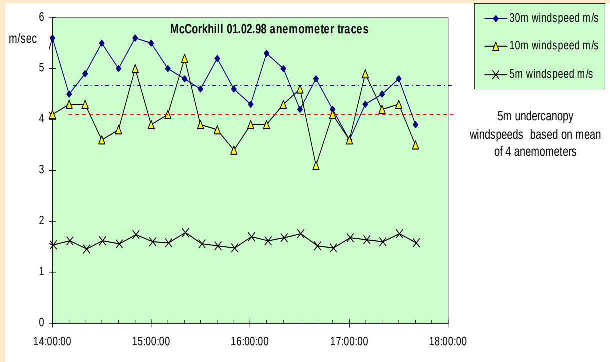

Wind profiles

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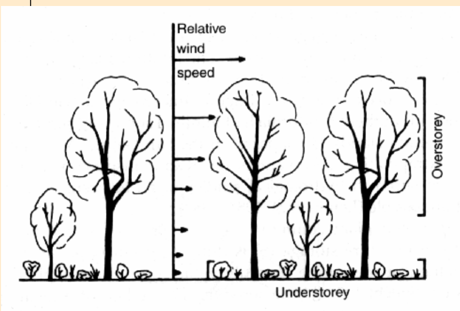

Location of measurement
10 m - in open
5m & 2m - under canopy

Ratio
10m : 5m 2.5:1
10m : 2m 3.0:1

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Weather observations

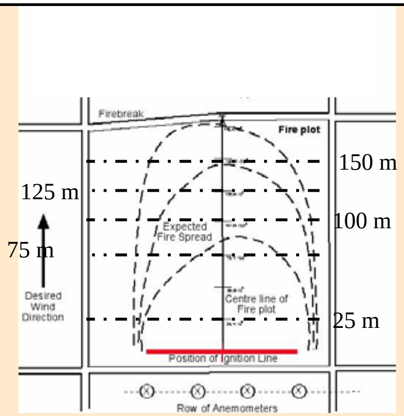
1. Weather observations made at a central location for each site (1 km radius of plots)
2. Wind at 30 m height
3. Air temp and RH
4. Upper atmospheric conditions (balloon and radiosonde)

Pre-fire measurements

1. Prevailing wind strength and Direction
2. Fuel moisture (50g grab sample)
   a) Surface litter
   b) Profile litter
   c) Bark
3. Fetch and exposure of individual anemometers

Experimental fires were ignited in a fixed 2 minute time period

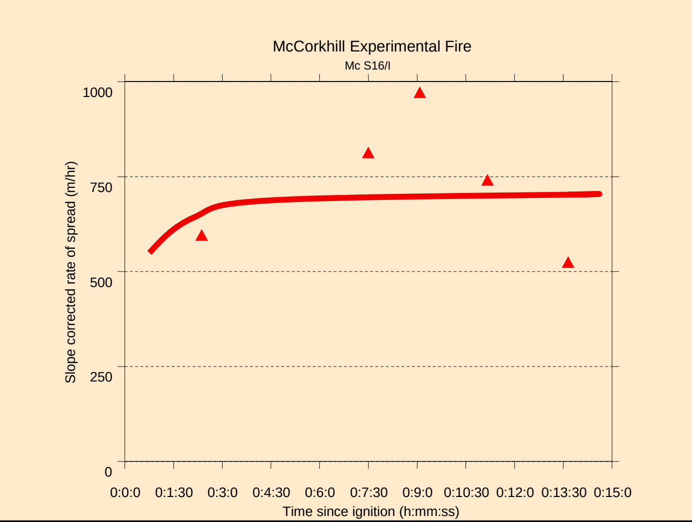

Ignition line 120 m



Fire spread measurements

Fire behaviour measurements

1. Rate of spread (spread lines tags thermologgers)
2. Flame height, flame angle (estimates)
3. Convective behaviour
4. Flame duration
   a) In-fire video (selected fires)
   b) Flame depth (where possible)
5. Spotting , smoke colour
6. Wind speed



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Post-fire measurement

1. Fuel moisture (surface litter)
2. Fire markers (head fire width, direction)
3. Slope change along axis of head fire
4. Calibration of anemometers (portable wind tunnel)

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Smoke studies

1. Smoke plume rise and dispersal were monitored by spotter aircraft
2. Data have been used to validate a model for smoke transport and dispersion (BoM – AFAC)

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Seasonal conditions for fire experiments

- Dee Vee (SDI >1800)
  1998 Feb 26 - March 17
  1999 Feb 23 - March 10
  2001 Feb 14 & 15
- McCorkhill (SDI 1260 - 1660)
  1999 Jan 11 - Feb 9

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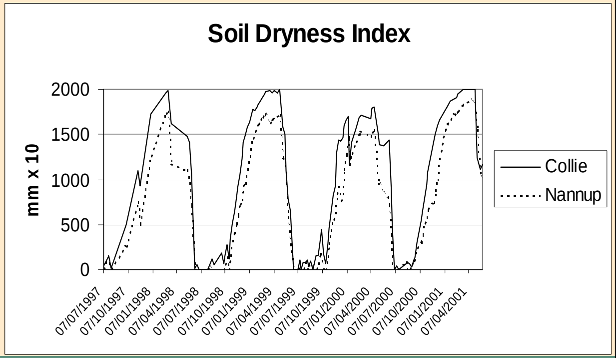
Seasonal trends in drought index 1998-2001



PROGRAM A

Project Vesta

Fire in Dry Eucalypt Forest:

fuel structure, fuel dynamics and fire behaviour

Assessment and application of fuel hazard rating system

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Department Environment and Conservation, WA
Phil Cheney
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Fuel - what it does

1. Determines the rate of spread and intensity of bushfires,
2. Determines the suppression difficulty of fires in different stages of fuel development in the forest,
3. Determines the bushfire threat or hazards of different forest types, and
4. Determines suppression resources needed and/or the frequency of hazard reduction.

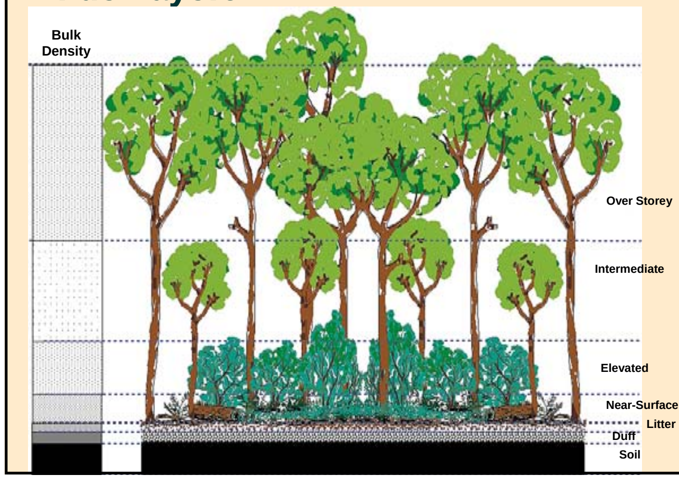
Fuel- how it changes

Fuel changes with time include:

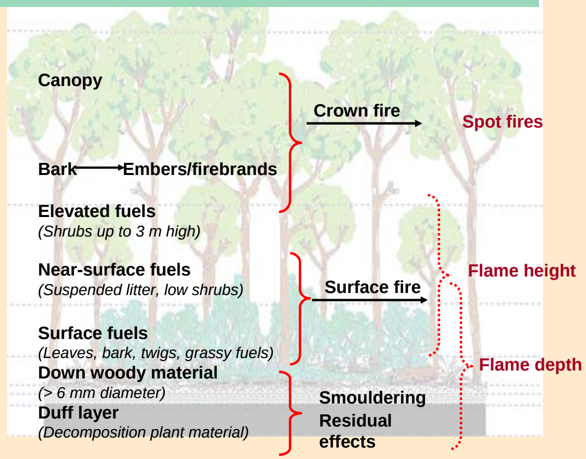
1. The total load after burning and as forests (and plantations) grow,
2. The volume of space occupied both horizontally and vertically (structure),
3. The proportion of fine and course fuel,
4. The proportion of live and dead fine fuel

Both load and structure are important to predict rate of spread, ease of suppression and threat.

Fuel layers



Fuel strata and flame structures



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Key attributes of fuel

1. The thickness of the fuel elements
2. Degree of horizontal and vertical continuity
3. The proportion of dead fine fuel in the fuel bed
4. The height of the most continuous fuel stratum

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Fuel hazard rating system

1. Fuel hazard rating systems to assess the fuel factors affecting fire behaviour and suppression difficulty
2. A technique emphasis the whole fuel complex - on all four fuel layers
3. Rating is visually obvious and can be applicable to any forest fuel type including dry eucalypt forest, conifer plantations and scrub or heath vegetation.
4. Based on:
   a) Cheney *et al* (1992)
   b) Wilson (1992, 1993)
   c) Tolhurst *et al* (1996)
   d) McCarthy *et al* (1999)
   e) Project Vesta scoring system
   f) Dept of Environment and Heritage, SA (2006).
5. **Fuel assessment field guide which integrates Project Vesta research findings with the Victorian Overall Fuel Hazard Guide**

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Fuel hazard rating system

Aim of the system is to:

1. to provide a simple and consistent method to assess the changes of fuel hazard in different vegetation or forest types after burning or as plantation forests develop with age,
2. to quantify the fuel hazards for fire suppression operations, and
3. to provide better estimates of potential fire threat.

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Fuel structure

1. Understorey structure
   a) Surface fuel
   b) Near-surface fuel
   c) Elevated fuel

2. Bark structure
   a) Bark type of different species can have a large impact on the rates of fuel accretion and on the generation of fire brands

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Surface fuel layer (SF)

- dead leaf, twigs and bark of the overstorey and understorey plants (litter fuel). The fuel components are generally horizontally layered. This layer usually makes up the bulk of the fuel consumed and provides most of the energy released by the fire. This layer burns both by flaming and smouldering combustion and determines the flame depth of a surface fire.

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Surface fuel layer (SF)

Hazard Rating	Description	Hazard Score	Litter depth (mm)*	Available fuel (t/ha)*
Nil	No surface litter, bare ground	**0**	-	0
Low	Very thin layer, no decomposition, discontinuous	**1**	<10	2-6
Moderate	Thin layer, no decomposition, continuous	**2**	10-20	6-10
High	Established litter layer, continuous, decomposing	**3**	15-25	10-14
Very High	Thick litter layer, continuous, decomposing, duff layer may be present	**3.5**	15-25	12-16
Extreme	Very thick continuous layer of litter, duff layer	**4**	>25	16+

Surface fuel: fuel hazard score

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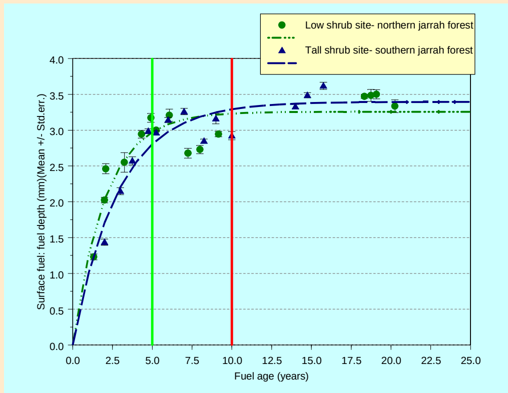

Surface fuel: fuel depth

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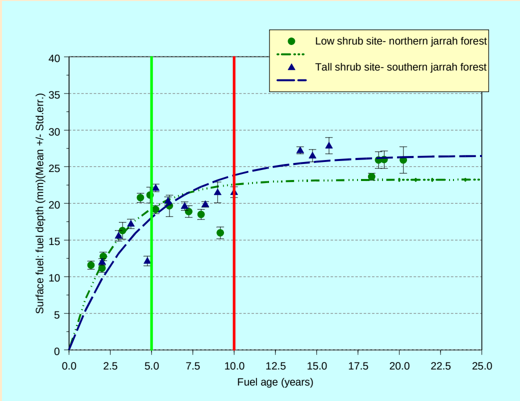

Surface fuel: fuel load

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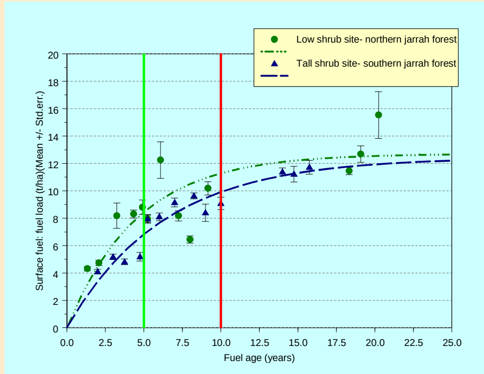
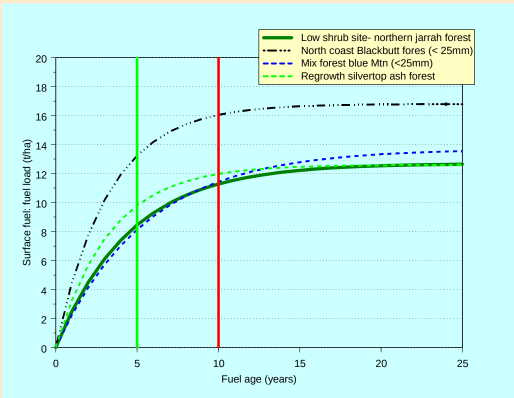


Surface fuel: fuel load

example of other fuel curves



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Near-surface fuel layer (NSF)

- grasses, low shrubs, creepers, and collapsed understorey usually containing suspended leaf, twig and bark from the overstorey vegetation. The height of this layer can vary from just centimetres to over a metre above the ground. The orientation of the fuel layer components includes a mixture ranging from horizontal to vertical and capable of supporting leaf, twig and bark material above the ground.

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Near-surface fuel layer (NSF)

Hazard Rating	Description	Hazard Score	Available fuel (t/ha)
Nil	No near-surface fuel	**0**	0
Low	Sparse dispersed fuel, dead material virtually absent	**1**	1
Moderate	Scattered suspended leaves, twigs and bark, proportion of dead material is <20%	**2**	2
High	Scattered suspended leaves, twigs and bark, starting to obscure logs and rocks, proportion of dead material is 20-50%	**3**	3
Very High	Lots of leaves and bark suspended, 40-60% cover in the 5 m radius	**3.5**	3.5
Extreme	Large amounts of leaves, twigs and bark suspend I the layer, high proportion of dead material >50%, vegetation is senescent, obscuring logs and rocks	**4**	4

Near-surface fuel: height

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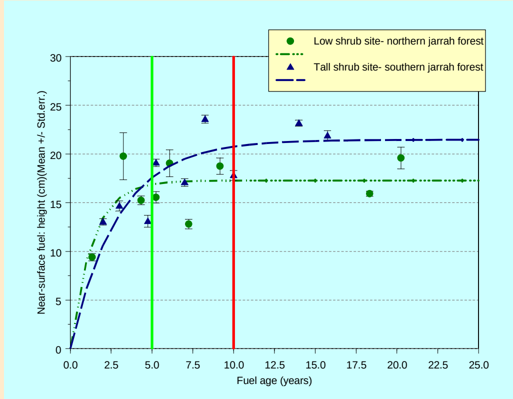

Near-surface fuel: fuel hazard score

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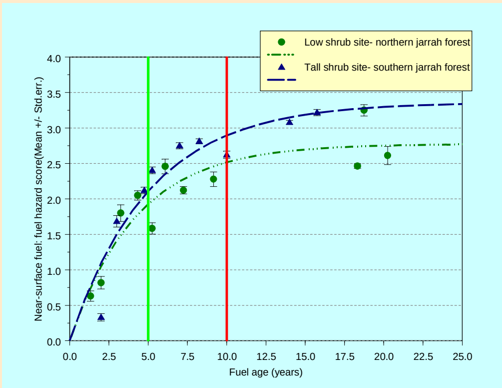

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Elevated fuel layer (EF)

– tall shrubs and other understorey plants without significant suspended material. This layer may include regeneration of the overstorey species intermixed with shrubs. The individual fuel components generally have an upright orientation and include live and dead material.

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Elevated fuel layer (EF)

Hazard Rating	Description	Fraction Dead (%)	Hazard Score	Available fuel (t/ha)
Nil	No elevated fuel	0	0	0
Low	Sparse and dispersed	< 5%	1	0-1
Moderate	Sparse and dispersed, brush against occasionally	< 20%	2	1-2
High	Little fine fuel at base, patchy or mesic shrubs	10-30%	3	2-3
Very High	Difficult to walk through, good vertical continuity of dead material	20+%	3.5	3-5
Extreme	Difficult to walk through, vertical continuity of fine dead fuel from ground up	30+%	4	5-8

Elevated fuel: fuel height

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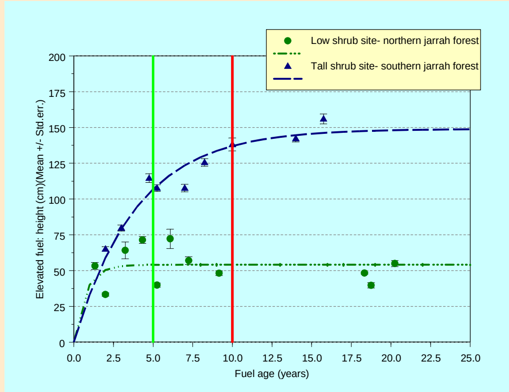

Elevated fuel: fuel hazard score

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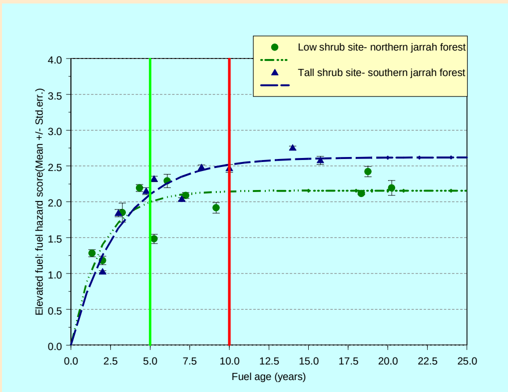

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Overstorey and Intermediate bark fuel (BF)

- the bark on the bole and branches, either alive or dead, extending right back to the cambial layer.
  - **a)** <u>**Smooth bark**</u> - as found on gum-barked eucalypts, characterised by the annual shedding of old bark layers and the exposure of a smooth living bark. Long strips of bark, half a meter or more fall off the stem and often drape over branches. This bark may burn for half an hour or more and is sometimes called "candle" bark.
  - **b)** <u>**Platy and sub-fibrous barks**</u> - as found on peppermints, box, bloodwoods, ironbarks, pines and deciduous hardwoods and characterised by layers of old, dead bark tightly held to the bole and branches, but capable of flaking and loosing small chunks as a result of burning or weathering.
  - **c)** <u>**Stringybarks**</u> - as found on stringybark and ash eucalypts and characterised by persistent old dead bark forming deep fissures and a relatively spongy fibrous mass and falling off in wads when very old or as a result of burning. Long-unburnt trees can produce massive amounts of burning embers.

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Overstorey and Intermediate bark fuel (BF)

Hazard Rating	Description	Hazard Score	Available fuel (t/ha)
Low	No fibrous bark, no spotting	**0**	0
Moderate	- stringybark where bark is well charred and tightly held on whole trunk - ironbarks with very tight, platy or fibrous bark -smooth-barks, which do not produce long ribbons of bark	**1**	1
High	- stringybark where most of bark is black on the lower trunk - few pieces of bark are loosely attached to trunks - bloodwood with tight fibrous bark which has not been burnt for many years - smooth / candle bark which shed long ribbons of bark but have smooth bark down to ground level	**2**	2

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Overstorey and Intermediate bark fuel (BF)

Hazard Rating	Description	Hazard Score	Available fuel (t/ha)
Very High	- stringybarks where <50% of surface area of the trees is black - upper parts of trunk may not be charred - smooth / candle barks with long ribbons of bark which are loose - fibrous or platy bark on lower trunk, which have not been burnt for many years	**3**	5
Extreme	- stringybark with large flakes of bark that can be easily dislodged - huge amounts of bark are available for spotting - outer bark on the trees is attached weakly - minimal evidence of charring (complete grey appearance on trunks)	**4**	7

3-year-old dry eucalypt fuel

SF FHS=1 (Low)
NSF FHS= 2 (Moderate)
EF FHS= 1 (Low)
Bark FHS= 1 (Moderate)
Overall fuel hazard= Low

5-year-old dry eucalypt fuel

SF FHS=3 (High)
NSF FHS= 2.5 (Moderate-High)
EF FHS= 1 (Low)
Bark FHS= 2 (High)
Overall fuel hazard= High

16-year-old dry eucalypt fuel

SF FHS=3 (High)
NSF FHS= 3 (High)
EF FHS= 2 (Moderate)
Bark FHS= 3 (Very High)
Overall fuel hazard= Extreme

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Mapleton Blackbutt forest

Long unburnt regrowth forest

SF FHS=4 (Extreme)
NSF FHS= 4 (Extreme)
EF FHS= 1 (Low)
Bark FHS= 3 (High)
Overall fuel hazard= High

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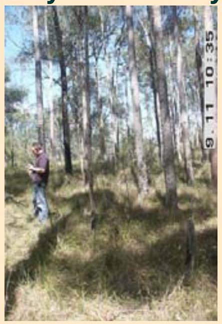
Dry eucalypt forest with grassy understorey



Previously prescribed burnt

SF FHS=1 (Low)
NSF FHS= 2 (Moderate)
EF FHS= 1 (Low)
Bark FHS= 2 (High)
Overall fuel hazard= Moderate

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Mountain /Manna Gum Forest

Long unburnt

SF FHS=4 (Extreme)
NSF FHS= 2 (Moderate)
EF FHS= 1 (Low)
Bark FHS= 1 (Low)
Overall fuel hazard= High

Summary

1. Visual fuel hazard rating provides an effective way to quantify changes in fuel structure as fuel develop with time since burning
2. Understorey fuels are co-related and increase with age in a similar pattern.
3. Time for the fuel to build up to its maximum level depends on:
   a) Fire intensity
   b) Degree of change to the vegetation structure
   c) Growth habits
4. No evidence of fuel characteristics of declining within 20 years of burning

Fuel hazard assessment application

1. Quantitative
   a) Selected fuel hazard values to predict fire behaviour
   b) Combined fuel hazard scores and fuel height to predict fire behaviour- rate of spread, flame height, spotting
2. Qualitative
   a) All fuel layer hazard ratings
      - Assess suppression difficulty
      - Assess bushfire risk and hazard to assets

PROGRAM A

Project Vesta

Fire in Dry Eucalypt Forest:

fuel structure, fuel dynamics and fire behaviour

Fire behaviour prediction

Lachie McCaw
Department Environment and Conservation, WA

Jim Gould
Ensis- CSIRO Bushfire Research Group, ACT

Phil Cheney
CSIRO Honorary Fellow, ACT

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Experimental steps

1. Take extensive measurements of fuel load and fuel structure.
2. Conduct simultaneous fires in different fuel ages over a range of wind speeds.
3. Rectify data to obtain ROS at a constant moisture content on head-fire width on level ground.
4. Correlate ROS with fuel variables in selected wind speed classes.

Experimental fires

range of burning conditions

	Low shrub	Tall shrub
Number of fires	53	63
5 m In-forest wind speed (m/s) 10 m Open wind speed (km/h)	0.97 - 2.86 8.7 - 25.7	0.80 - 2.37 7.2 - 21.5
Temperature (°C)	21 - 31	22 - 34
Relative Humidity (%)	27 -53	26 - 51
Surface FMC (%)	6.0 - 8.6	5.6 - 10.5
Profile FMC (%)	6.1 - 19.1	5.5 - 9.5

Experimental fires Observed fire behaviour

Fuel age (years)	Slope (degrees)	Rate of spread (m/hr)	Flame height (m)	Fire Intensity (kW/m)
2 -3	-1.0 - 4.0	0.0 - 390	0.1 -3.0	0.0 - 1340
5 - 6	-2.5 - 13	112 - 1364	0.1 - 15.0	400 - 6160
8 - 9	-2.0 - 4.0	66 - 974	0.2 - 20.0	385 - 4200
11 - 16 (MC)	-1.0 - 4.0	295 - 1240	0.5 - 22.0	2320 - 10570
19 - 22 (DV)	0.0 - 4.0	47 - 800	0.2 - 8.0	275 - 5430

McCorkhill block Jan 1999
Experimental fires in 16, 11 & 8 year-old fuel

Assumptions for modelling

1. An ignition line 120 m wide would produce a fire spreading at its potential ROS,
2. The mean wind measured at 5 m by 4 anemometers >20 m behind ignition line would represent the mean wind blowing across the block over the duration of the fire,
3. Existing relationships describing the effect of slope and moisture on ROS could be used to normalise the data.

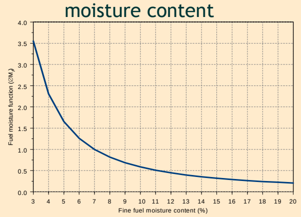
Data rectification

1. Remove data from negative slopes and over-run from steep slopes.
2. Normalise ROS data from positive slopes to ROS on level ground using McArthur slope function (Noble, Bary & Gill 1980).

Data rectification

1. Remove data after rain when litter profile is moisture affected (>10%)
2. Normalise ROS data to surface fuel moisture content of 7% using function of Burrows (1999)
3. Analyse wind variation in block

ROS as a function of surface moisture content



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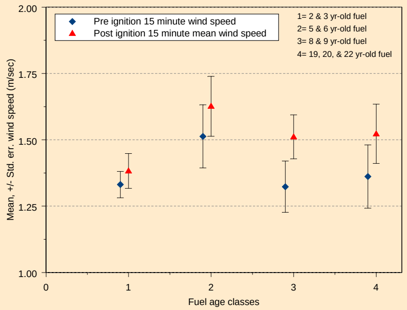
Increase in wind following ignition

Dee Vee Pre / Post 5 m wind speed averages



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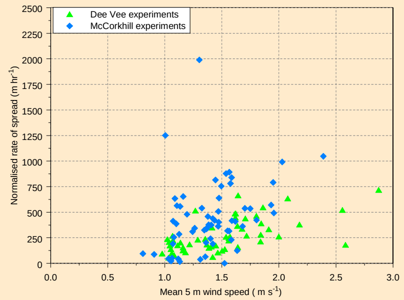
ROS in relation to wind speed at zero slope and 7% surface moisture content



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Fuel variables strongly correlated with rate of spread

1. Bark fuel
   a) Intermediate bark hazard score: (.59)
2. Elevated fuel
   a) Fuel hazard score (.65)
   b) FHS x height (.63)
3. Near-surface fuel
   a) **FHS x height (.69)**
   b) Fuel hazard score (.65)
4. Surface fuel
   a) Fuel hazard score (.57)
   b) Percent cover score (.54)

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Surface fuel load

1. Strongly correlated to ROS at low winds
2. Poor relationship with ROS at moderate winds
3. Did not integrate data from low and tall shrub sites (separate relationships needed).

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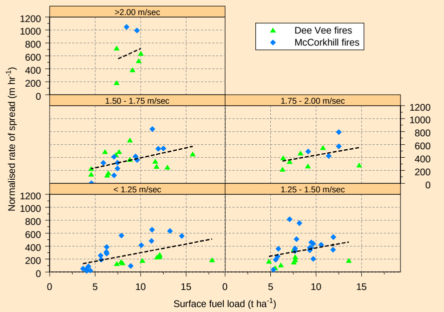
ROS plotted against surface fuel load for 5 wind classes



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Near-surface fuel:

Fuel hazard score x fuel height

1. Strong correlation with ROS at low and moderate wind speeds
2. Better integration of data from low shrub and tall shrub sites
3. Outliers are fires on steep slopes in 5 y.o. fuel.

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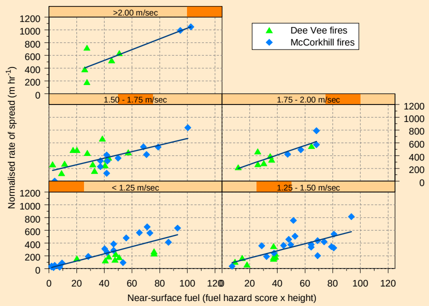
ROS plotted against NSF (hazard score x height) for 5 wind classes



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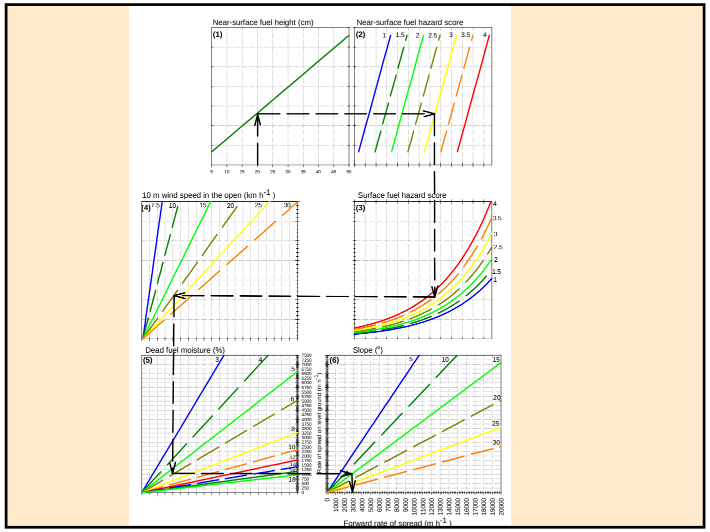
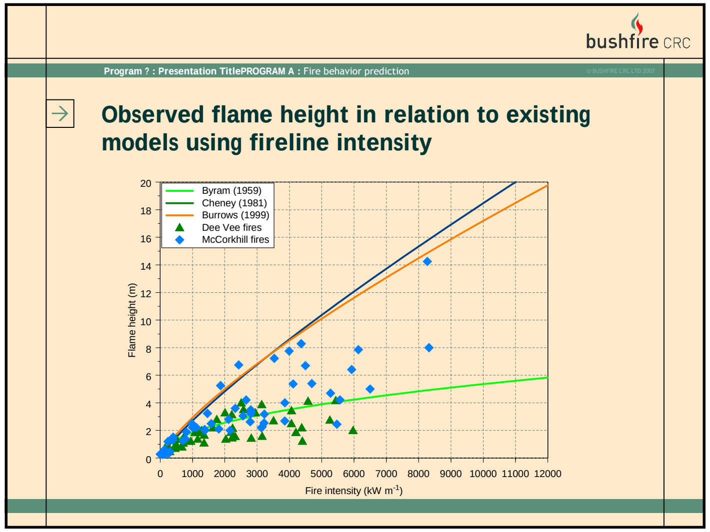
New fire spread model

1. Predicts rate of headfire spread as a function of:
   - fine fuel moisture,
   - wind speed,
   - surface fuel hazard score, and
   - combined variable of near-surface fuel hazard and height.
2. Represents potential rate of spread of an established line of fire.
3. Fires will burn below their potential rate of spread during initial stages of development:
   - until the headfire is at least 100 m wide (typically 1-2 hours), and
   - if the width of the headfire is constrained.


Near-surface fuel height (cm)
Near-surface fuel hazard score
10 m wind speed in the open (km h-1)
Surface fuel hazard score
Dead fuel moisture (%)
Slope (°)
Forward rate of spread (m h-1)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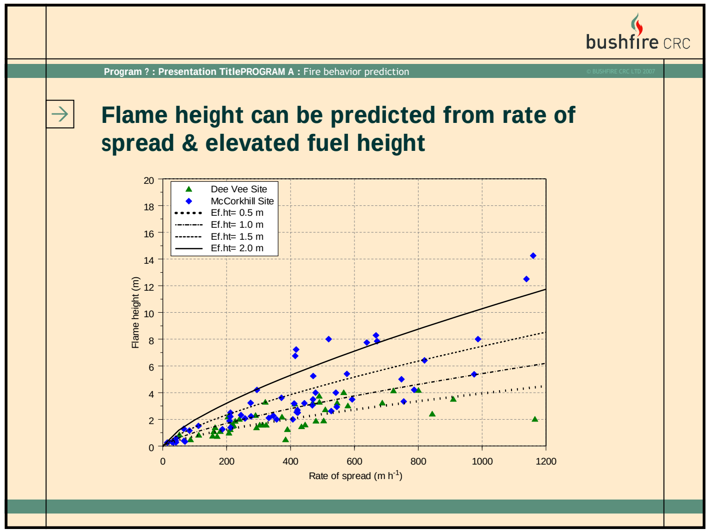
Program ? : Presentation TitlePROGRAM A : Fire behavior prediction
Observed flame height in relation to existing models using fireline intensity
Byram (1959)
Cheney (1981)
Burrows (1999)
Dee Vee fires
McCorkhill fires
Flame height (m)
Fire intensity (kW m-1)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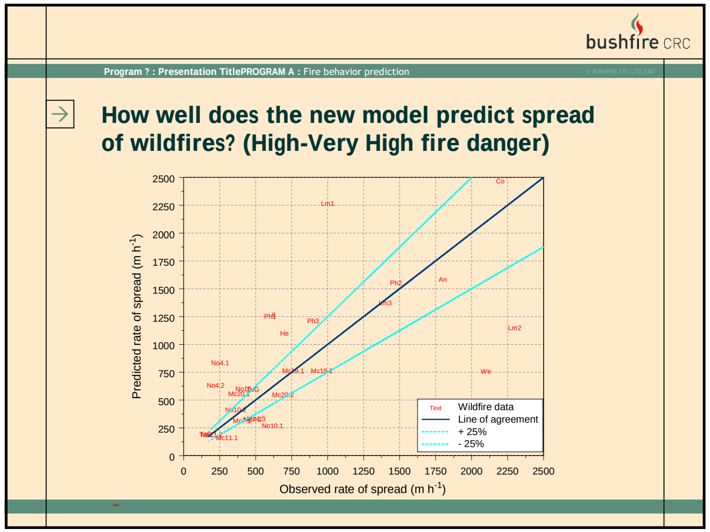
Flame height can be predicted from rate of spread & elevated fuel height
Dee Vee Site
McCorkhill Site
Ef.ht= 0.5 m
Ef.ht= 1.0 m
Ef.ht= 1.5 m
Ef.ht= 2.0 m
Flame height (m)
Rate of spread (m h-1)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Program ? : Presentation TitlePROGRAM A : Fire behavior prediction
How well does the new model predict spread of wildfires? (High-Very High fire danger)
Wildfire data
Line of agreement
+ 25%
- 25%
Predicted rate of spread (m h-1)
Observed rate of spread (m h-1)

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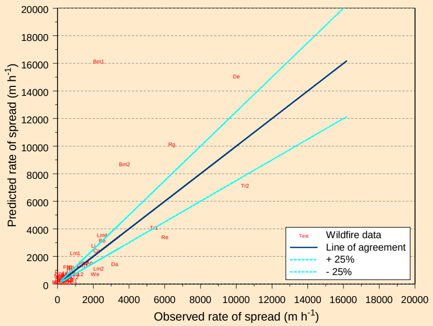
How well does the new model predict spread of wildfires? (including Extreme fire danger)



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What about the existing fire behaviour guides?

1. WA Forest Fire Behaviour Tables and McArthur prescribed burning guide remain valid for predicting the behaviour of prescribed burns lit from point ignition sources under mild burning conditions
2. Existing FDI retained for
   - public warning of fire danger
   - setting preparedness levels (detection, standby)

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Effectiveness of hazard reduction by prescribed burning

1. Hazard reduction by prescribed burning will reduce the rate of spread, flame height and intensity of a fire, as well as the number and distance of spotfires by changing the structure of the fuel bed and reducing the total fuel load
2. Even when the surface fuel and understorey layers have stabilised the hazard score rating of fibrous-barked trees will continue to increase and will increase the difficulty of suppression

Spotting/firebrands – understanding, measurement, modelling and prediction

Peter Ellis, Jim Gould
Bushfire Research, ensis, ACT

Project FuSE SA

Significance

1. Loss of control/suppression costs (McCarthy and Tolhurst 1998) by breaching control lines, by increasing number of fires, possibly also by increasing fire ros (Tolhurst and MacAulay 2003)
2. House loss (Barrow 1944, Ramsay and McArthur 1995, to Leonard et al 2000+), as well as risk models (Wilson 1984, Tolhurst and Howlett 2003)
3. Urban/suburban fire spread, including following nuclear holocaust (Christiansen 1969, Huang et al. 2007)

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Spotting, firebrands, transported debris

1. Firebrands are potential spotfires, probability of ignition dependent on fuel and weather
2. Structure ignition by firebrands may be very protracted and may also involve transported unburnt material
3. Transport may be wind alone, including along ground, or include lofting by convection, thermals, vortices, topography effects

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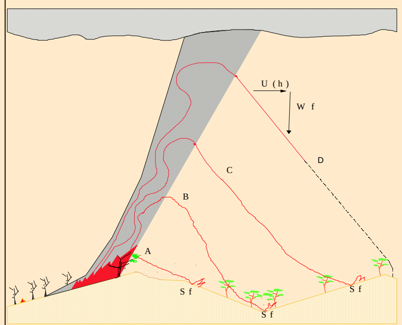
Involves Conditions and Processes



Vortices?
Thermals?
Topography?
Chance

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Conditions

1. Firebrands: numbers, size distribution (may be fire and FFMC dependent) and characteristics
2. (Fire behaviour: flame dimensions, flame residence time, convection dimensions and velocity, turbulence, especially variations over time (updraft, downdraft)
3. Ambient wind over topography, T, RH
4. Fuel bed, particle diameter, FFMC

Problems in predicting

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1. Complexity, interactions, unknowns
2. Difficulty of obtaining adequate data/observations
3. Difficulty in interpreting data/observations
4. Difficulty in testing models

Example: did spotfires at ~ 200+ m result from convection/wind (with subsequent change in wind direction), or from vortices?

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Conditions - variation in fire behaviour

u. d.

break in fuel

d. d.

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Processes

1. Firebrand ignition
2. (Detachment and descent in wind-field, thermals?)
3. Detachment and entrainment
4. Lofting and retention
5. Exit/ejection
6. Descent in wind-field, thermals?
7. Fuel-bed ignition (land on fuel, still combusting sufficiently)
8. Spotfire continues burning, then overcome or remains independent

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Spotfire independence, or feed-back to fire

Spotfires often drawn back to fire-front, need to be beyond critical distance to be independent (Muraszew and Fedele 1976)

Mass spotting may effectively increase fire ros (McArthur 1967, Tolhurst and MacAulay 2003)

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Interactions and complexities – many fire and fuel characteristics interact

1. Greater wind speed gives greater ros, fire intensity, lofting power, and transport potential
2. Also increases flame height and number of firebrands likely to be lofted
3. However, greater convection strength may mean more chance of fb retention and burn out in plume (Lee and Hellman 1969)
4. Greater wind speed may facilitate ignition of fuel-bed

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Relative Importance of Conditions and Processes

Some results from two studies:

- Saltus 1998-2001 (Commission of European Communities research - Fr. Gr. Italy, Port. And Spain) – 250 fires, heath, open woodland, coniferous and hardwood forest, Thematic Final Report 2001 and paper Ed D.X. Viegas 2002
- Vesta 1996-2001 (Calm, csiro) ~ 90 fires, dry sclerophyll

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Saltus data (studied 11 veg types, aimed to develop probabilistic model)

1. Weather
2. Vegetation main fire
3. Topography
4. Fire behaviour: ros, flame length, convection column, smoke colour (often estimates)
5. (Degree of certainty)

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Saltus results: Some strong trends, large variation, anomalies

Influence of maximum wind speed

Max wind speed	Number fires	%, S > 10m	%, S > 100 m	Maximum S
Less than 18 km/hr	32	38	0	80
18-36 km/hr	44	66	23	375
Greater than 36 km/hr	105	78	48	1100

Wind affects fire intensity and transport. Max wind speed more significant than Mean, which may reflect irregular phenomenon (pulses, torching)

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Saltus results

Influence of fuel load

F Fuel load t/ha	Number	%, S > 10 m	%, S > 100 m	Max S
Less than 10	62	19	18	400
10 - 30	113	62	30	1050
30 - 50	71	75	46	1200
More than 50	22	86	64	2000

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Saltus all fires: the percentage of fires spotting at distances > 10m, and > 100m, increased with;

1. Flame length, Ros, Fire intensity
2. Average and max wind speed, air temp
3. Slope of emitting zone
4. Height of trees
5. Tree cover
6. Tree diameter
7. Fuel load

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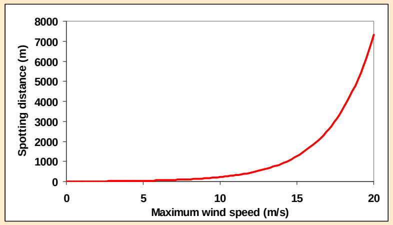
Saltus results: within vegetation types, the significant factors varied widely

For example, for eucalypt forest, the only significant factor influencing spotting distance was maximum wind speed.



One problem with analysis within vegetation type possibly small amount of data

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Some Saltus results

1. Most spot fires occur when fire spreads principally due to wind
2. Most due to crown fires
3. Where there are fire whirls (vortices), spotfires occur simultaneously
4. FFMC almost always below 11%

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Saltus probabilistic model

Example:

'If wind > 40 km/hr, conifer tree density > 100 per ha, FFMC < 20%, fire area > 50 ha, then spotfires will occur at distances between 200 m and 300 m in 80% of fires.'

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Project Vesta correlations - spotfire numbers

(Spotfire numbers given rank (0 to 5) from field notes.) Expected factors are shown to be significant in correlation matrix.

	10m wind	sf.fhs	os.fhs	Max.Flame.ht	Mean I(Burrows)	mean ROS
sf.fhs	0.28	1.00				
os.fhs	0.27	0.77	1.00			
Max.Flame.ht	0.20	0.52	0.31	1.00		
Mean I(Burrows)	0.24	0.44	0.25	0.90	1.00	
mean ROS	0.50	0.58	0.40	0.64	0.72	1.00
Spotfire Numbers	0.40	0.55	0.46	0.57	0.54	0.55

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Project Vesta correlations - max spot distance

	sf.fhs	os.fhs	Flame.Depth	Max.Flame.ht	Max I (Burrows)	max ROS	Max distance
os.fhs	0.77	1.00					
Flame.Depth	0.48	0.41	1.00				
Max.Flame.ht	0.52	0.31	0.78	1.00			
Max I (Burrows)	0.44	0.26	0.76	0.99	1.00		
max ROS	0.47	0.28	0.40	0.47	0.42	1.00	
Max spot distance	0.32	0.31	0.51	0.21	0.18	0.11	1.00

Only factor shown to have much significance is Flame Depth. However, Fl Dpth is also correlated with Intensity (linear regression gives R^2 of 0.58). Conclusion: spotting is complex.

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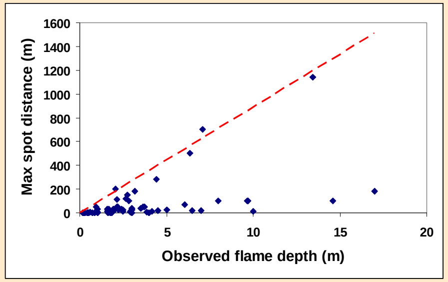
Project Vesta - flame depth effect

This graph appears to show that the maximum possible spotting distance appears to correlate strongly with Flame Depth. However, deep flames do not necessarily result in long distance spotting.



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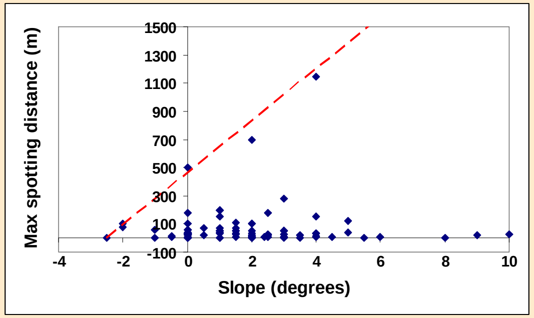
Project Vesta -slope effect

Seems to be a similar effect of Slope



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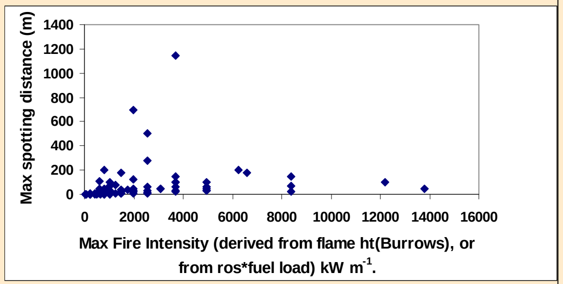
Project FuSE SA

Project Vesta - fire intensity effect



Distances up to ~ 200 m from wide range of intensities, greater distances all from limited range.

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Project FuSE SA

Project Vesta data - coincidences or 'real'? For Spotting distances > ~ 250 m;

1. Max fire intensities between 3000 and 6000 kW m^{-1}
2. Windspeeds between 15 and 17 km hr^{-1}
3. Max possible distance appeared to increase as Slope increased
4. However, little data for distances > 200 m

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Generally

1. Bigger fires can spot further, spot more
2. Long distance spotting requires firebrand release from convection
3. appears to req

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What was spotting mechanism? Convection/wind (then change in wind direction), or vortices?

SHRUBLAND FIRE BEHAVIOUR - OVERVIEW

Wendy Anderson
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Northcott Drive, ACT

Abstract:

This lecture looks at the work of the Heathland Fire Behaviour Group prior to the beginning of the Bushfire CRC in bringing together data from heathland burns from Australia and New Zealand, as well as from some international sources. It describes the state of knowledge of fire behaviour in heathland in 2003. It also discusses the extra information that we perceived that was needed to develop an empirical fire behaviour model for heathland that would meet management objectives as well as increase our understanding of fire behaviour in this complex vegetation type.

Suggested reading:

Catchpole, W.R., Bradstock, R.A., Choate, J., Fogarty, L.G., Gellie, N., McCarthy, G.J., McCaw, W.L., Marsden-Smedley, J.B., and Pearce, G. (1999). Cooperative development of equations for heathland fire behaviour. Proceedings of the 3rd International Conference on Forest Fire Research, Luso, Portugal.

Catchpole, W.R., Bradstock, R.A.., Choate, J., Fogarty, L.G., Gellie, N., McCarthy, G.J., McCaw, W.L., Marsden-Smedley, J.B., and Pearce, G. (1999). Cooperative Development of Prediction Equations for Fire Behaviour in Heathlands and Shrublands. Australian Bushfire Conference, Albury, July 1999. http://www.csu.edu.au/special/bushfire99/papers/catchpole/

Cruz, M. Viegas, D.X. (1998). Fire behaviour in some common Central Portugal fuel complexes: evaluation of fire behaviour models. 3rd International Conference on Forest Fire Research, Luso, Portugal.

Davies, G. M. (2005). Fire behaviour and impact on heather moorland. PhD thesis. University of Edinburgh.

Fernandes, P.M. (2001). Fire spread prediction in shrub fuels in Portugal. Forest Ecology and Management 144: 67-74.

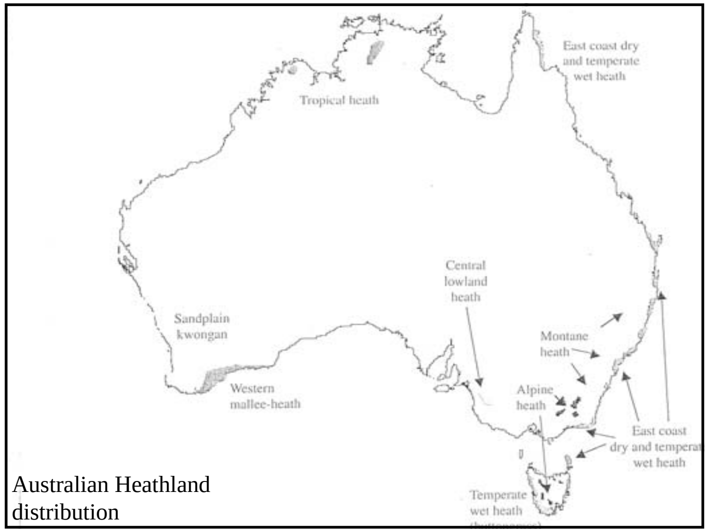
McCaw, L. (1991). Fire spread prediction in mallee-heath shrublands in South-Western Australia, Proceedings, 11th conference on fire and forest meteorology.

Marsden-Smedley, J.B., & Catchpole W.R. (1995) . Fire behaviour modelling Tasmanian buttongrass moorlands. II. Fire behaviour. Int. J. Wildland Fire 5, 215-228.

Sauvagnargues-Lesage, S., Dusserre, G. Robert,F., Dray, G. and Pearson, D.W. (2001). Experimental validation in Mediterranean shrub fuels of seven wildland fire rate of spread models. Int. J. Wildland Fire 10: 15 – 22

Vega, J.A., Cuiñas, P. Fontúrbel, T., Pérez-Gorostiaga P. and Fernandes, C. (1998). Predicting fire behaviour in Galician (NW Spain) shrubland fuel complexes. Proceedings of the 3rd International Conference on Forest Fire Research, Luso, Portugal.


Shrubland fire behaviour –
an overview
Wendy Anderson
School of PEMS
UNSW@ADFA


Tropical heath
East coast dry
and temperate
wet heath
Central
lowland
heath
Sandplain
kwongan
Montane
heath
Western
mallee-heath
Alpine
heath
East coast
dry and temperat
wet heath
Temperate
wet heath
Australian Heathland
distribution


Alpine


Coastal


Wetland

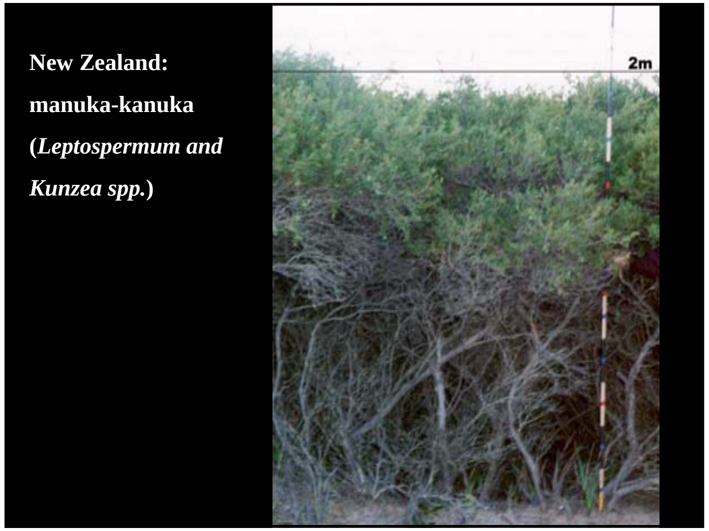

Montaine


Hawkesbury sandstone


WA *Eucalyptus* mallee form with shrub understorey.


Tasmanian buttongrass moorland.


New Zealand:
gorse (*Ulex europeanus*)


New Zealand:
manuka-kanuka
(*Leptospermum and Kunzea spp.*)
2m

Heathland Fire Behaviour Research Group

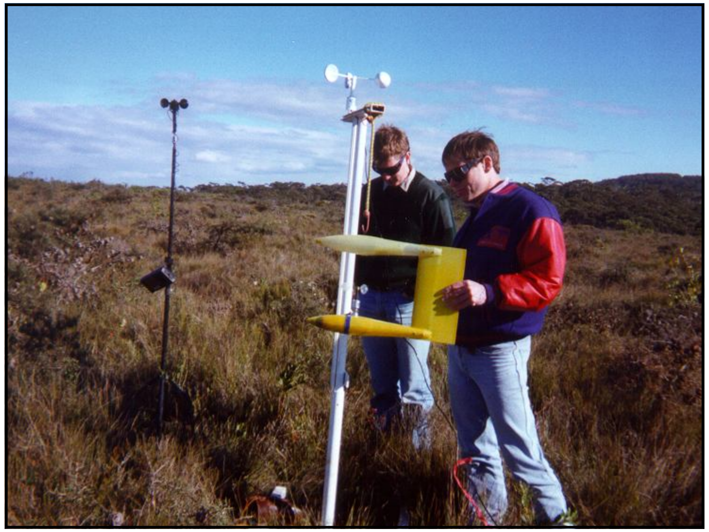
Inter-agency, international
co-operative research

Victoria, Tasmania, South Australia, Western Australia

New South Wales

New Zealand

Portugal, Spain, France, Scotland



Heathland fire data

117 experimental fires
16 wild fires

Maximum 2m wind speed 35 km/hr
Maximum spread rate 60 m/min

Shrubland fire research

-systems needed for:

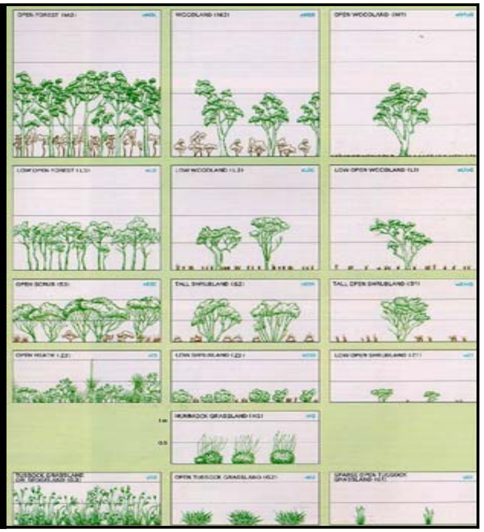
fuel characteristics
fire behaviour

- rate of spread and flame height
- fire danger rating
- intensity
- conditions for extinction

Fire management systems

•Fuel characteristics

Specht (1970) **classification**



Fire management system

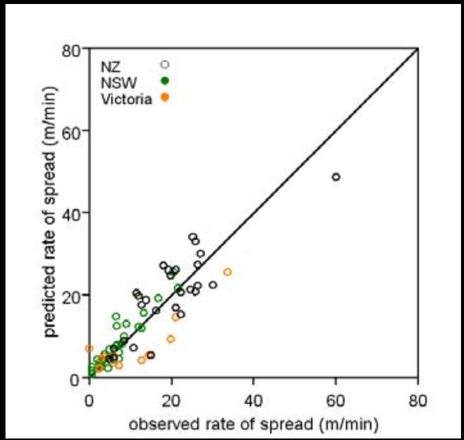
- **Fire behaviour**
  - * **spread rate**

Eastern Australian and New Zealand data.

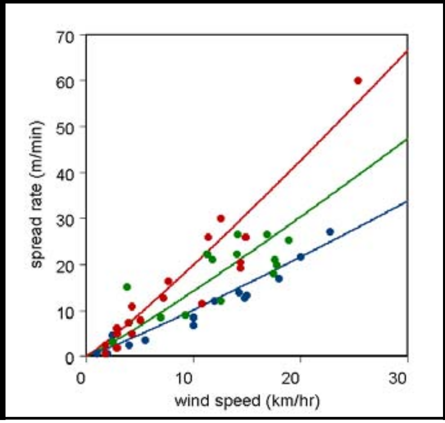
Fitted model: $ROS = 0.8\,U^{1.1}H^{0.49}$

ROS = rate of spread (m/min)
U = 2m wind speed (km/hr)
H = vegetation height (m)

Fitted model (experimental fires)



Effect of wind speed and fuel height



4 meter

2 meter

1 meter

MOISTURE EFFECTS

Heathland: none found (M >10%)

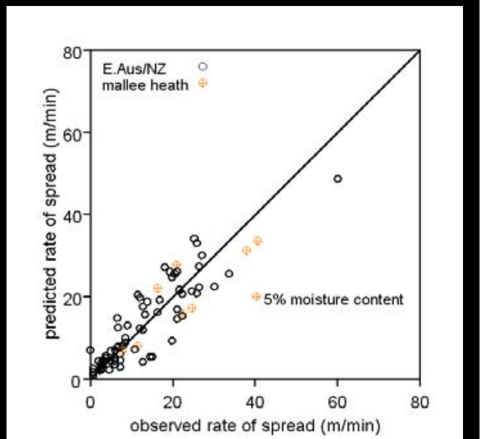
Grassland: exp(-0.11M)

Moorland: exp(-0.02 M)
effect only for dead fuel moisture greater than 40% (soaking wet fuel).

WA mallee: exp(-0.12 M)
predominant effect for litter fuel moisture less than 6%.

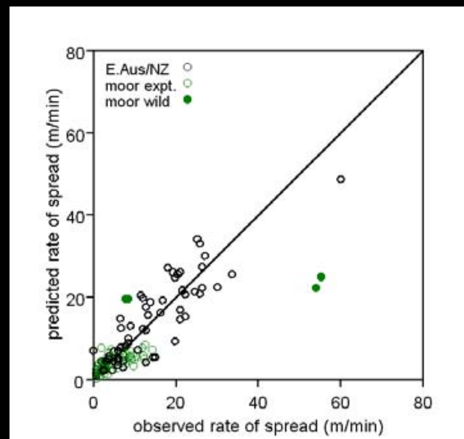
WA mallee fires

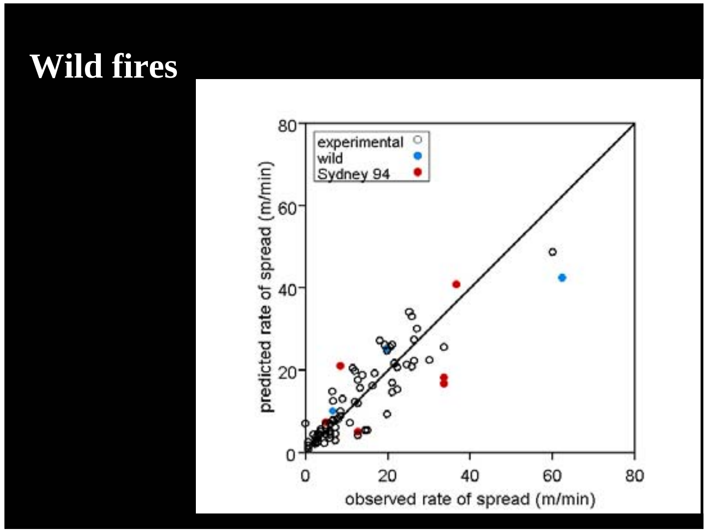
nominal 3m height



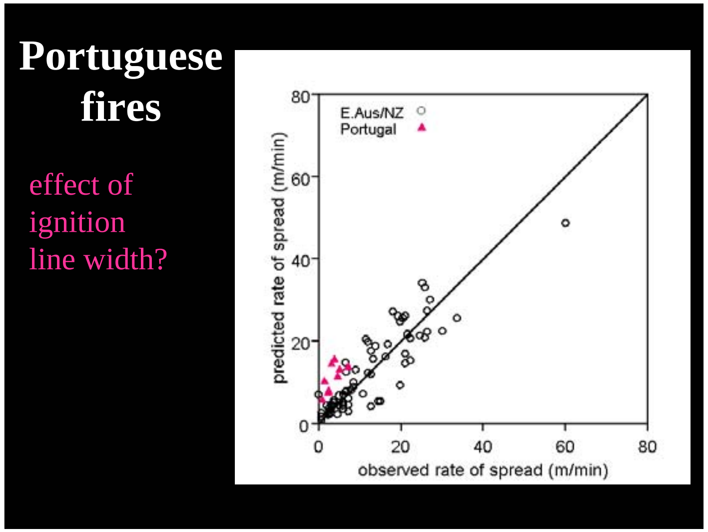
Buttongrass moorland

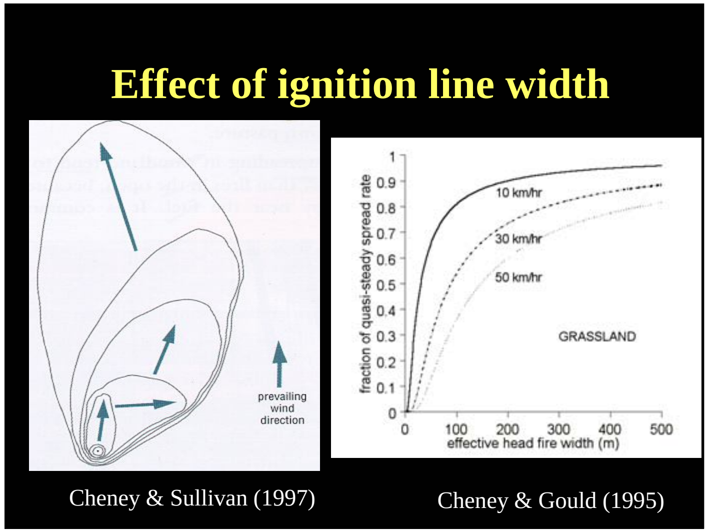
Sedgey heaths may spread faster




Wild fires
experimental
wild
Sydney 94
predicted rate of spread (m/min)
observed rate of spread (m/min)
0
20
40
60
80


Experimental fires
in Portugal


Portuguese fires
effect of
ignition
line width?
E.Aus/NZ
Portugal
predicted rate of spread (m/min)
observed rate of spread (m/min)
0
20
40
60
80


Effect of ignition line width
prevailing wind direction
10 km/hr
30 km/hr
50 km/hr
GRASSLAND
fraction of quasi-steady spread rate
effective head fire width (m)
Cheney & Sullivan (1997)
Cheney & Gould (1995)

SLOPE

McArthur forest meter slope effect

$$R = R_0 \exp(0.069\,A)$$

R_0 = zero-slope spread
A = slope angle

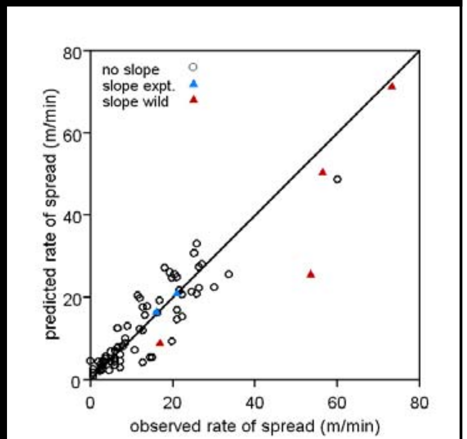
Slope effect for NZ fires (experimental and wild)

$$R = R_0 \exp(0.035\,A)$$

NZ urban interface
Wellington
- wildfire in gorse

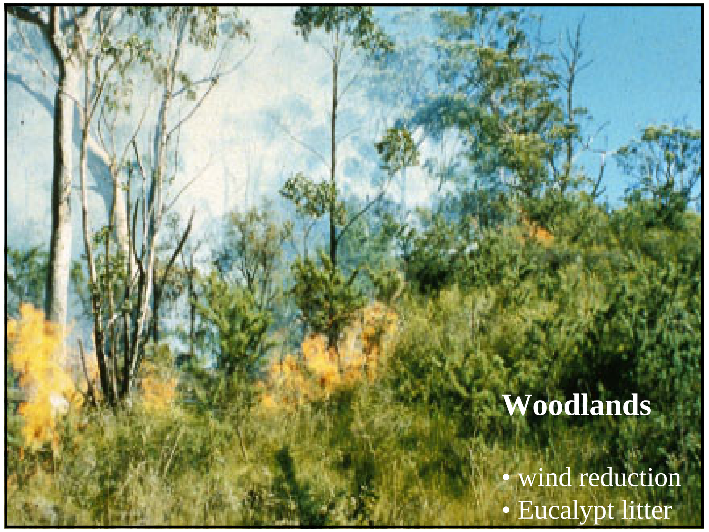
experimental burn

Slope effect



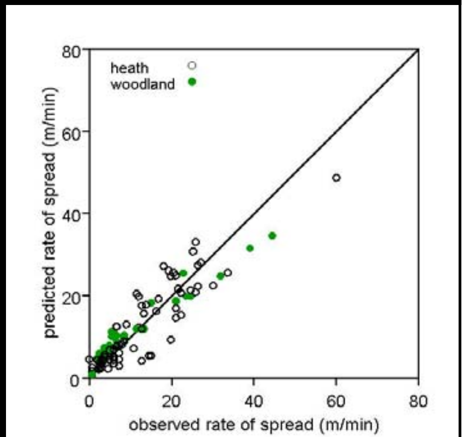
Slope experiments in Portugal

EU project INFLAME



Woodlands

wind speed
reduction
factor
(Tran 1999)



Fire management system

Fire behaviour

* spread rate
* intensity

INTENSITY:

(heat per meter of fireline)

Byram (1959)

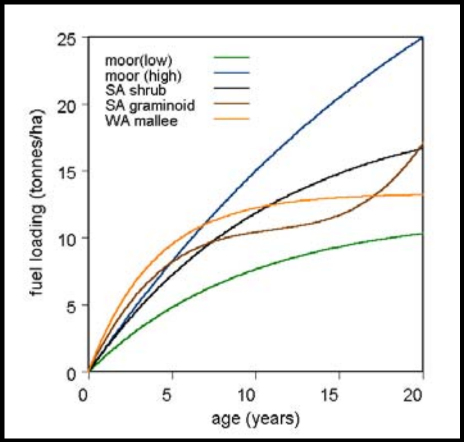
$$I_B = H\, w_a\, R$$

I_B = Byram's intensity
H = heat of combustion
w_a = available fuel
R = rate of spread

suppression difficulty
flame length
vegetation damage

BIOMASS ACCUMULATION

Specht 1981	SA mallee/heath
Conroy 1993	Sydney sandstone
Marsden-Smedley & Catchpole 1995	Buttongrass moorland
McCaw 1998	WA mallee

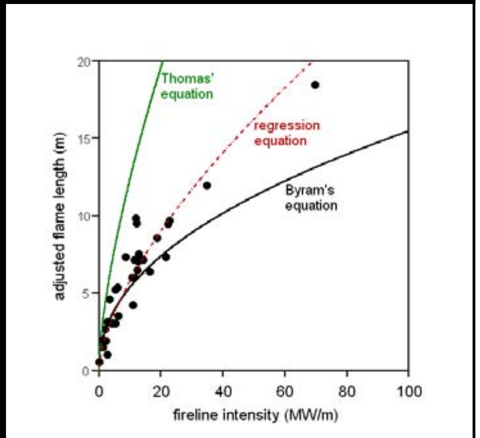


Fire management system

Fire behaviour

* spread rate
* intensity
* flame length

Flame length model



$L_{adj} = 0.0153\ I_B^{\ 0.65}$

Fire management system

- **Fire behaviour**
  - * spread rate
  - * intensity
  - * flame length
  - * ignition and extinction

Go/No-go criteria

Moorland: **probability of burning depends on windspeed, moisture content, and productivity/load/continuity**
Marsden Smedley, Catchpole and Pyrke (2001)

WA Mallee: **probability of burning depends on moisture content of the deep litter.**
McCaw (1998)

Logistic equation

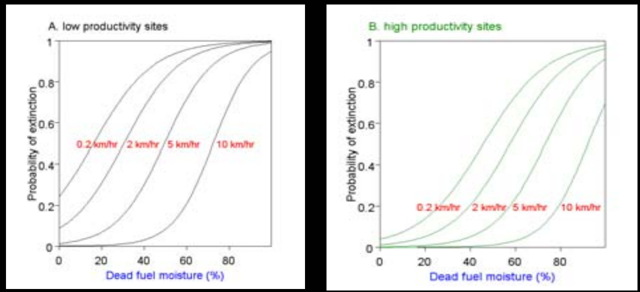
$$\log(p/(1-p)) = a + bU + cM + dU*M + eP$$

p = probability of extinction
U = wind speed
M = moisture content
P = productivity

effect of moisture is less at higher wind speeds (d<0)

Fires are also non-sustaining when fuel age is less than 3 years.

Extinction in moorlands



Marsden-Smedley et al. (2000)

Unbounded burning

Future work

- slope effect
- moisture effect
- species effect
- ignition line length effect
- high intensity experimental fires
- wind reduction in woodland
- moisture content - heath
  -woodland
- fuel accumulation for intensity
- ignition probability

SHRUBLAND FIRE BEHAVIOUR – PROJECT FUSE: NEW ZEALAND UPDATE

Grant Pearce
Ensis - Forest Biosecurity and Protection, SCION
Christchurch, New Zealand

Abstract:

Shrubland fuels are highly flammable, demonstrating dramatic increases in fire spread and intensity with changes in wind speed and fuel moisture as a result of their large amounts of dead, fine fuels and elevated, open structures. New Zealand has a history of research on shrub and heathland fire behaviour that has seen investigation of a range of approaches to development of fire spread models, most recently as part of the Bushfire CRC's fire behaviour research program. Project FuSE (Fire Experiments in Scrub, with attention to wind 'u') aims to continue development of a heath/shrub fire behaviour model by conducting experimental fires in different heath/shrub/scrub fuel structures at sites in Australia and New Zealand across a range of burning conditions. A secondary objective of the New Zealand burns is investigation of the effect of slope on fire behaviour for shrubland fuels.

This presentation will describe the present state of knowledge on fire behaviour in New Zealand shrubland fuel types and linkages with operational decision support tools, and the research currently being conducted within Project FuSE, including the successfully completed New Zealand experimental fires at Lake Taylor and the planned experiments at Torlesse Station in Canterbury.

Suggested reading:

Anderson, S. 2005. Forest and rural fire danger rating in New Zealand. In: Colley, M. (ed.). Forestry Handbook. New Zealand Institute of Forestry, Christchurch. pp 214-244.

Anderson, S.A.J. 2006. Future options for fire behaviour modelling and fire danger rating in New Zealand. Paper No. 75, presented at the Bushfire Conference 2006, Brisbane, 6-9 June 2006. 6 p. CD-ROM.

Fogarty, L.G.; Pearce, H.G.; Catchpole, W.R.; Alexander, M.E. 1998. Adoption vs. adaptation: lessons from applying the Canadian Forest Fire Danger Rating System in New Zealand. In: Proceedings, 3rd International Conference on Forest Fire Research and 14th Fire and Forest Meteorology Conference, Luso, Coimbra, Portugal, 16-20 November, 1998. pp 1011-1028.

Catchpole, W.; Bradstock, R.; Choate, J.; Fogarty, L.; Gellie, N.; McCarthy, G.; McCaw, L.; Marsden-Smedley, J.; Pearce, G. 1998. Cooperative development of equations for heathland fire behaviour. In: Viegas, D.X. (editor). Proceedings, 3rd International Conference on Forest Fire Research and 14th Fire and Forest Meteorology Conference, Luso, Coimbra, Portugal, 16-20 November, 1998. pp 631-645.

Alexander, M.E. 1994. Proposed revision of fire danger class criteria for forest and rural areas in New Zealand. National Rural Fire Authority, Wellington, in association with the New Zealand Forest Research Institute, Rotorua. 73 p.

SHRUBLAND FIRE BEHAVIOUR – PROJECT FUSE: AUSTRALIAN UPDATE

Miguel Cruz and Juanita Myers
Bushfire Research Group
Ensis - Forest Biosecurity and Protection, CSIRO
Yarralumla, ACT

Abstract:

This aim of this study is to develop models to support prescribed burning in South Australian mallee and heath fuel types. The research is investigating fuel accumulation through time, fuel moisture and wind dynamics, as well as modelling fire behaviour, namely rate of spread, flame characteristics, and the fire environment conditions that will sustain fire propagation (go/no-go).

Fourty-eight experimental burns have been carried-out in 7 to 48 year old mallee and heath fuels under 10-m wind speeds ranging from 6 to 25 km hr^{-1}; and surface fuel moisture contents between 5 and 20%. The mallee and heath fuel types exhibited very different fire behaviour, with the threshold for sustained fire propagation being lower in the heath fuel type. Fire dynamics in the mallee fuel complex were characterised by sharp discontinuities in fire behaviour, with abrupt increases in fire behaviour for relatively small changes in the associated wind and fuel moisture conditions. For this fuel type, spotting was a critical factor for sustained fire propagation under moderate burning conditions. In the lower range of burning conditions, the factors that limited fire spread in both fuel types appeared to be the low bulk density of the shrub component and the overall fuel patchiness.

Suggested reading:

Bradstock, R.A.; Cohn, J.S. 2002. Fire regimes and biodiversity in semi-arid mallee ecosystems. In: Flammable Australia: the fire regimes and biodiversity of a continent. (eds R.A. Bradstock, J.E. Williams and A.M. Gill) Cambridge, UK: Cambridge University Press: 238-258.

Bradstock, R.A.; Gill, A.M. 1993. Fire in semi-arid Mallee shrublands: size of flames from discrete fuel arrays and their role in the spread of fire. Int. J. Wildland Fire 3: 3-12.

Keith, D.A.; McCaw, W.L.; Whelan, R.J. 2002. Fire regimes in Australian heathlands and their effetcs on plants and animals. In: Flammable Australia: the fire regimes and biodiversity of a continent. (eds R.A. Bradstock, J.E. Williams and A.M. Gill) Cambridge, UK: Cambridge University Press: 199-237.

McCaw, W.L. 1997. Predicting fire spread in Western Australian mallee heath shrubland. PhD thesis. Canberra, Australia: University of New South Wales, University College, School of Mathematics and Statistics. 235 p.

McCaw, W.L.; Burrows, N.D.; Friend, G.R.; Gill, A.M. 1995. Predicting fire spread in Western Australian mallee-heath. In: Proceedings, Landscape Fires '93:

Proceedings of an Australian Bushfire Conference, Perth, Western Australia. 27-29 September 1993. CALM Science, No. 4 Supplement: 35-42.

McCaw, W.L. 1998. Research as a basis for fire management in malee-heath shrublands of south-westren Australia. Pages 2335-2348 in the Proceedings of 3rd International Conference on Forest Fire Research – 14th Conference on Fire and Forest Meteorology, Luso - Coimbra, Portugal - 16/20 November 1998.

Myers, J., Gould, J., Cruz, M.G., Henderson, M. 2007. Fuel dynamics and fire behaviour in Australian mallee and heath vegetation. In: Butler, Bret W.; Cook, Wayne, comps. 2007. The fire environment— innovations, management, and policy; conference proceedings. 26-30 March 2007; Destin, FL. Proceedings RMRS-P-46. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 7 p. CD-ROM.

Noble, J.C. 1984. Mallee. In: Management of Australia's Rangelands. (eds G.N. Harrington, A.D. Wilson, and M.D. Young) Melbourne, Australia: CSIRO: 223-240.

Noble, J.C. 1986. Prescribed fire in mallee rangelands and the potential role of aerial ignition. Aust. Rangel. 8(2):118-130.

Plucinski, M.P. 2003. The investigation of factors governing ignition and development of fires in heathland vegetation. PhD thesis. Canberra, Australia: University of New South Wales, Australian Defence Force Academy, School of Mathematics and Statistics. 347 p.

bushfire CRC

Project Fuse: Fuel dynamics and fire behaviour in Australian mallee and heath vegetation

Miguel Cruz and Juanita Myers
Ensis Forest Biosecurity and Protection CSIRO, Canberra, Australia
Bushfire CRC, East Melbourne, Australia

Government of South Australia
Department for Environment and Heritage

ensis

CSIRO

scion

Acknowledgements:

Bushfire CRC, East Melbourne, Australia
www.bushfirecrc.com

Department for Environment and Heritage, South Australia
www.environment.sa.gov.au

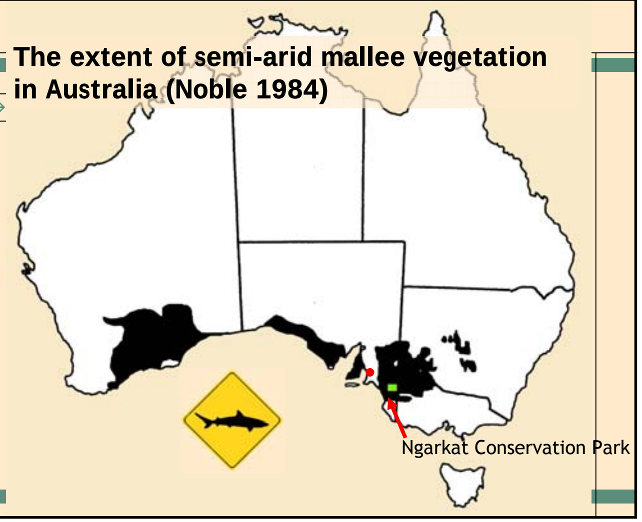
Summary:

bushfire CRC

- Background / Fire history
- Project FuSE objectives
- Experimental design
- Preliminary results
- Future work

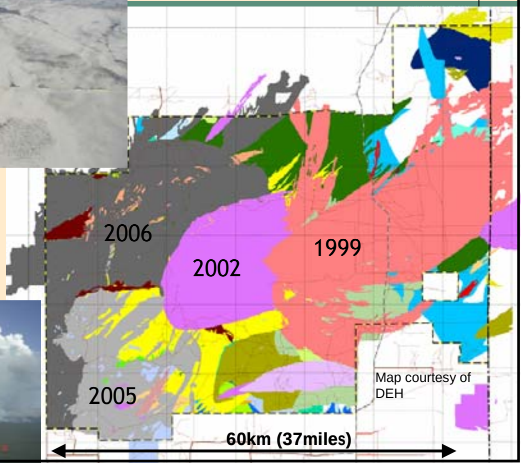
Aim:
To produce a prescribed burning guide for mallee and heath fuel types.

The extent of semi-arid mallee vegetation in Australia (Noble 1984)



Ngarkat fire history

bushfire CRC



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Specific objectives

1. Fuel structure changes with time;
2. Fuel moisture;
3. Vertical wind profiles;
4. Fire behaviour
   a) Propagation threshold (go / no-go);
   b) Rate of spread, flame characteristics;
   c) Flame radiometric properties/heat flux

Burning Experiment – Plot Layout

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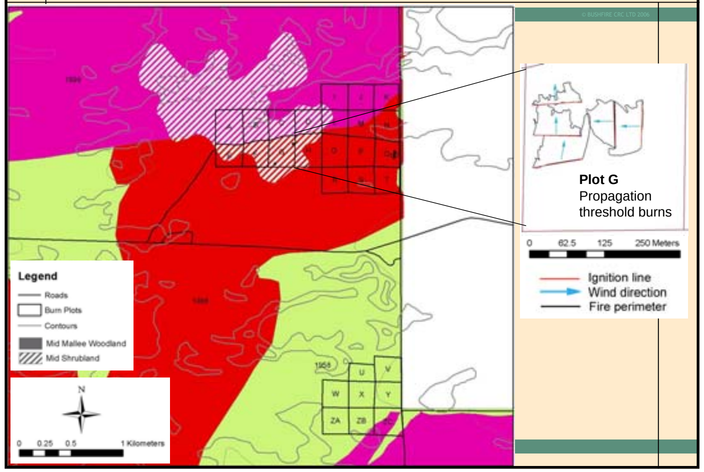

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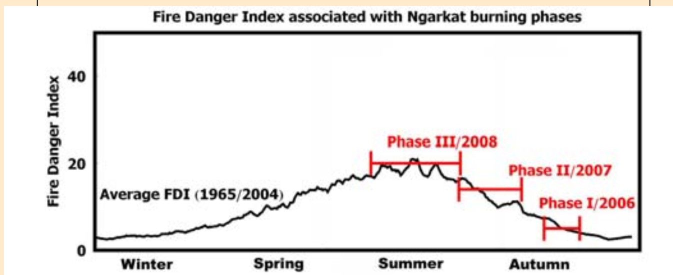
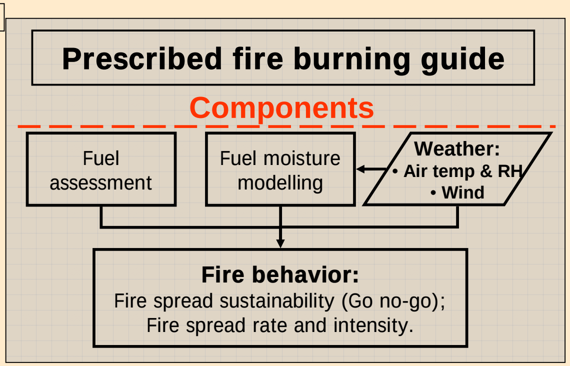
Experimental design



Preliminary results

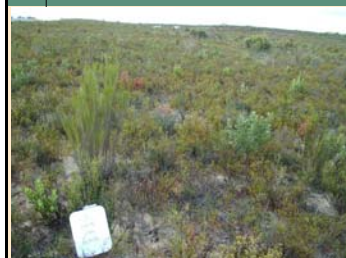


Fuel types

7 year old mallee

20 year old mallee

48 year old mallee

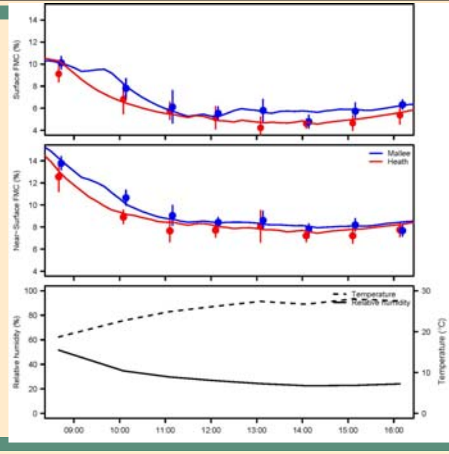


7 year old heath

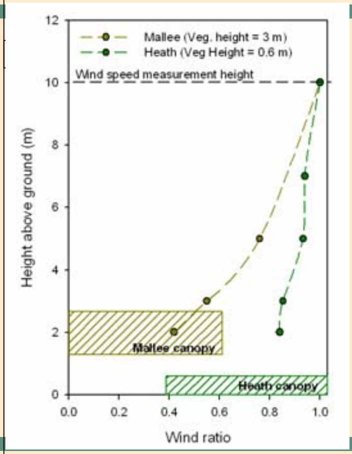
20 year old heath

Preliminary results – fuel structure

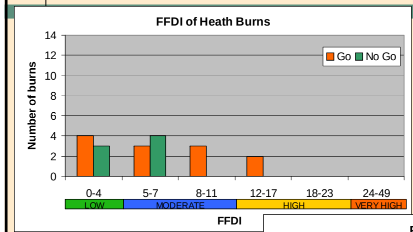
Preliminary results – fuel moisture

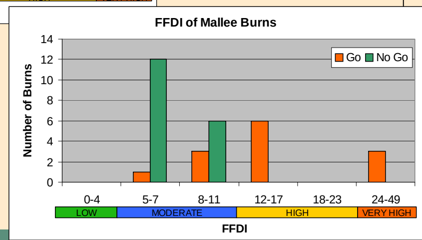


Preliminary results – wind profile



Preliminary results – fire behaviour





Preliminary results – fire behaviour

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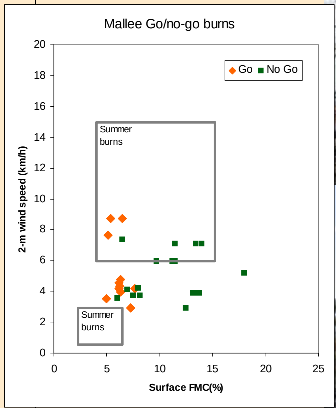

Fire Behaviour – concurrent burns

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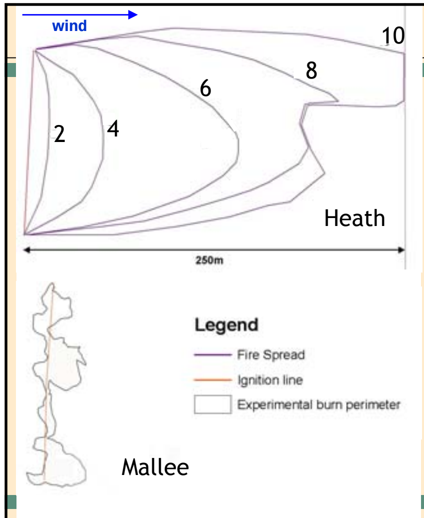

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Fire Behaviour – 20 year old fuels

Temp. = 20°C
RH = 37%
5-m wind = 15km/h

Rate of Spread:
Heath: 30.8 m/min
Mallee: 0.5 m/min

Preliminary results – fire behaviour

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Play infire video

Preliminary results – flame temperature

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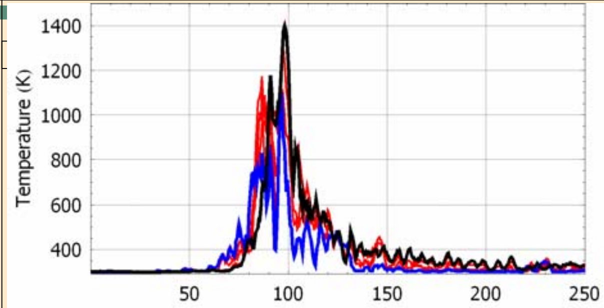

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Completion of this project:

1. Burning phase III – more of the same but **hotter!**
   a) FFDI between 13 and 49;
   b) Fire suppression - effectiveness of aerially delivered suppressants;
2. Write up report and develop field guide + software

Follow-on work:

1. Technology transfer
2. Model evaluation

PINE PLANTATION FIRE BEHAVIOUR

Miguel Cruz
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Ensis - Forest Biosecurity and Protection, CSIRO
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Abstract:

The development of a model system for the prediction over the full range in fire behaviour in exotic pine plantation fuel types in relation to environmental conditions is described. The proposed system integrates a series of sub-models describing surface fire characteristics and crowning potential properties (e.g., onset of crowning, type of crown fire and associated rate of spread). The main inputs are wind speed, fine dead fuel moisture content, and fuel complex structure, namely surface fuel bed characteristics, canopy base height and canopy bulk density. The detail with which the model system treats surface and crown fire behaviour allows users to quantify stand "flammability" with stand age for particular silvicultural prescriptions.

The application of the model to a radiata pine plantation thinning treatment case study in Victoria is presented. The results highlight the complex interactions that take place between fire behaviour and attendant fuel and weather conditions. The structural changes introduced in the fuel complex by the treatment altered fire behaviour, but no definite reduction and/or increase in rate of fire spread was identified. The results illustrate the role that simulation models can play in support of silvicultural and fuel management decision making.

Suggested reading:

Alexander, M.E. 1998. Crown fire thresholds in exotic pine plantations of Australasia. Ph.D. Thesis, Australian National University, Canberra, Australia. 228 p.

Alexander, M.E., Cruz, M.G. 2006. Evaluating a model for predicting active crown fire rate of spread using wildfire observations. Canadian Journal of Forest Research 36: 3015-3028.

Alexander, M.E., Cruz, M.G., Lopes, A.M.G. 2006. CFIS: a software tool for simulating crown fire initiation and spread. In the Proceedings of 5th International Conference on Forest Fire Research, Figueira da Foz, Portugal - 27/30 November 2006.

Burrows N.D. 1980. Quantifying Pinus radiata slash fuels. Forests Department of Western Australia. Research Paper 60. 6 p.

Burrows, N.D., Ward, B. & Robinson, A. 1988. Aspects of fire behaviour and fire suppression in a Pinus pinaster plantation. West. Aust. Dep. Conserv. Land Manage. Landnote 2/99.

Burrows, N.D., Ward, B., Robinson, A. 2000. Behaviour and some impacts of a large wildfire in the Gnangara maritime pine (Pinus pinaster) plantation, Western Australia. CALMScience 3(2):251-260.

Cruz, M.G., Butler, B.W., Alexander, M.E. 2006. Predicting the ignition of crown fuels above a spreading surface fire Part II: Model behaviour and evaluation. Int. J. Wildland Fire 15(1):61-72.

Cruz, M.G., Fernandes, P., Alexander, M.E. 2007. Development of a model system to predict wildfire behaviour in pine plantations. In the Proceedings of 2007 Institute of Foresters of Australia and New Zealand Institute of Forestry Conference, 3rd- 7th June, 2007. Coffs Harbour, NSW. Pages 119 – 128.

Cruz, MG, Alexander, ME, and Wakimoto, RH (2005) Development and testing of models for predicting crown fire rate of spread in conifer forest stands. Canadian Journal of Forest Research 35: 1626-1639.

Cruz, MG, Butler, B.W., Alexander, M.E., Forthofer, J.M., Wakimoto, R.H. 2006. Predicting the ignition of crown fuels above a spreading surface fire I: Model idealization. Int. J. Wildland Fire 15(1):47-60.

Fernandes, P.M.; Botelho, H.S.; Loureiro, C. 2002. Models for the sustained ignition and behaviour of low-to-moderately intense fires in maritime pine stands. In: Forest Fire Research & Wildland Fire Safety. Proceedings of the IV International Conference on Forest Fire Research/2002 Wildland Fire Safety Summit. (ed. D.X. Viegas) Rotterdam, The Netherlands: Millpress Scientific Publications. [CD-ROM]. 11 p.

Palheiro, P., Fernandes, P.A. Cruz, M.G. 2006. A fire behavior-based fire danger classification for maritime pine stands: comparison of two approaches. In the Proceedings of 5th International Conference on Forest Fire Research, Figueira da Foz, Portugal - 27/30 November 2006.

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Pine plantation fire behaviour

Miguel Cruz
Ensis Biosecurity and Protection
Bushfire Research, Ensis - CSIRO

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CSIRO scion
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Presentation outline:

1. Issues / knowledge gaps;
2. Fuel dynamics;
3. Fire behaviour modelling;
4. Concluding remarks.

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Fire in exotic pine plantations

1. Fuel complex characteristics:
   a) Moderately compacted litter layer;
   b) Vertical discontinuity;
   c) Dense canopy layer;
   d) Flammable foliage.
2. Within stand microclimate.
3. Fire characteristics:
   a) Fire propagation driven by flame front properties;
   b) Crown fire propagation.

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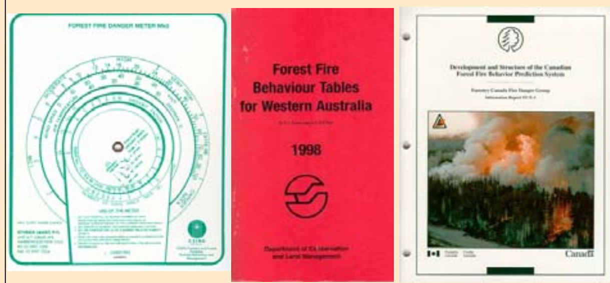
Issues/knowledge gaps (1)



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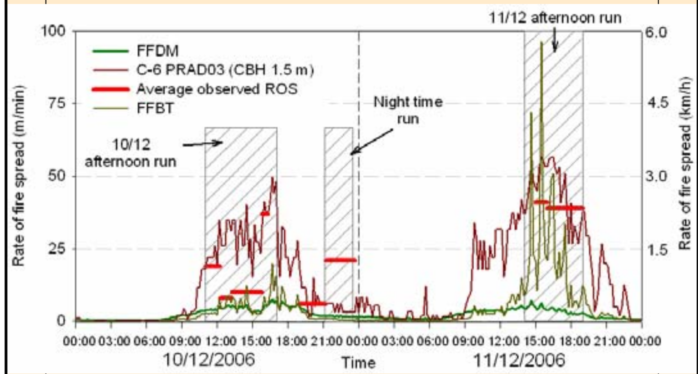
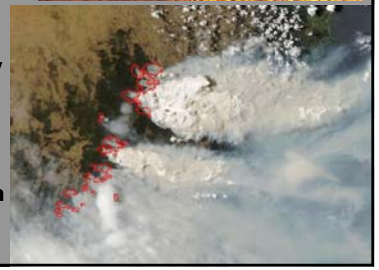


Issues/knowledge gaps (2)

Crown fire propagation:

- Wide range in fire spread: 10 - 100 m/min (0.6 - 6 km/h - 150-200 m/min in extreme cases);
- High energy release rates – flame heights up to 40 m;
- Source of prolific spotting activity;

- Level of fire behaviour that normally precludes any direct suppression action;
- Responsible for large proportion of area burned;
- Effects not consistent with ecological sustainability.



Onset of crowning: effect on fire spread

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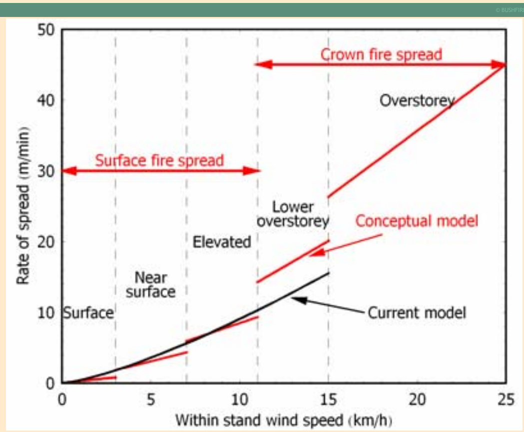
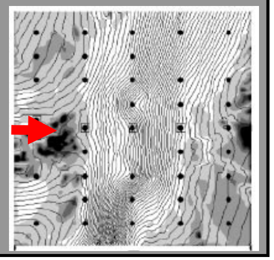


Onset of crowning: effect on fire spread

1. "...when crowning did occur, then fire spread rates were **2-5 times** that of ground [surface] fires" (Burrows et al. 1988);
2. Fernandes et al. (2004) measured a near **double** increase in rate of spread from a plot experiencing a high-intensity surface fire with tree torching to a plot where crowning was continuous.
3. ICFME plot 8 (Taylor et al. 2004):

Phase	ROS (m/min)	U10 (km/h)
1 (C)	24.3	11.0
2 (S)	5.6	8.3
3 (C)	54.0	14.3

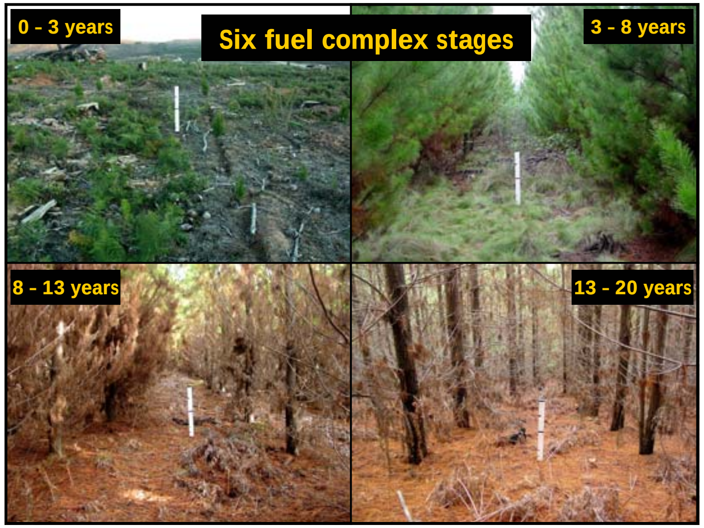


Objective

1. **Develop a model system aimed at predicting the rate of spread and other associated fire behaviour characteristics in pine plantations;**
2. **Desired attributes:**
   a) Applicability over the full spectrum of fire behaviour;
   b) Adequate quantitative description of fire behaviour factors and processes determining crown fire propagation;
   c) Explicit inclusion of the effects of relevant fuel complex variables.

Fuel complex dynamics

- large changes throughout rotation;
- exceptionally “flammable” at certain stages **but** at the same time amenable to fuel modification.



Important stages (fire behaviour assessment):
- canopy closure;
- development of ladder fuel layer;
- start of surface fuel buildup;
- increase of fuel strata gap;
- silvicultural interventions.

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Table 3. Sampled and estimated surface and canopy fuel properties for selected fuel complex stages of radiata pine plantations, Buccleuch State Forest, Tumut, NSW.

Fuel complex stage	Fuel load (Tons/ha): Litter L layer	Litter F - H layer	Other fine[1]	Live fuels[2]	Coarse fuels[3]	Canopy live fuels	Canopy bulk density (kg/m³)	Fuel strata gap (m)	Canopy base height (m)
PRAD02 (7 years)	0.6	0	7.7	2.2	0	12	0.21	0.5	0.8
PRAD03 (10 years)	1.6	1.9	4.6	0	0	10	0.15	1.5	4.7
PRAD04 (15 years)	3.8	4.4	0.3	0	2.4	10	0.11	10.5	10.5
PRAD04T[4] (15 years)	3.8	4.4	3	0	13	6	0.07	10.5	10.5
PRAD05 (30 years)	3.3	7.7	0.6	0	5	10	0.1	16	16
PRAD06[5] (fresh)	3.3	8	14	0	27	-	-	-	-

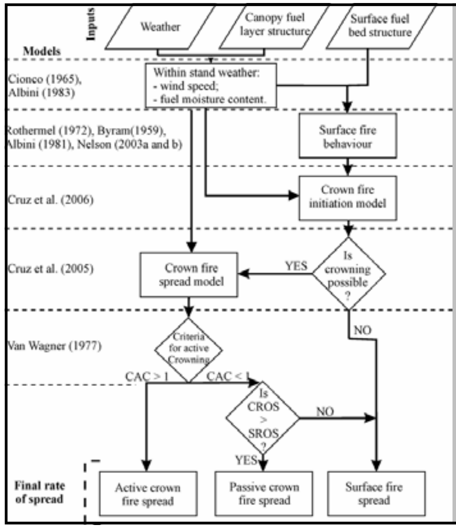
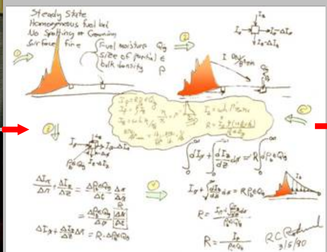
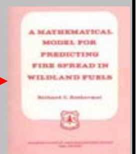


Diagram of information flow for fire behaviour in pine plantations

Surface fire spread model: Rothermel (1972)

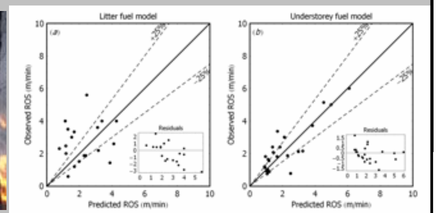
- Semi-empirical fire spread model;
- Calibrated for pine plantations (*P. Pinaster*);
- Evaluated against experimental fire data/models in radiata pine plantations.





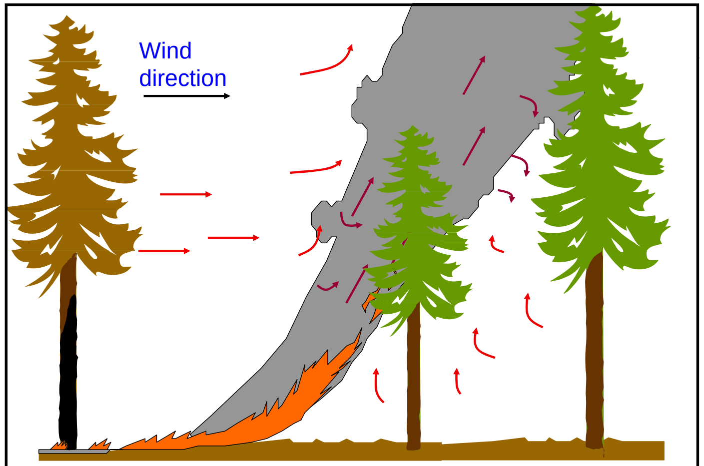
Calibration for pine plantations (*P. Pinaster*) based on backtracking method:

- Dataset of 42 prescribed and experimental fires (ROS: 0.6 – 6.7 m/min; Fire intensity: 70 – 1300 kW/m);
- We need to find the physical fuel description (fuel model) that will minimize error;
- Systematic search of possible solutions from a set of input variables.

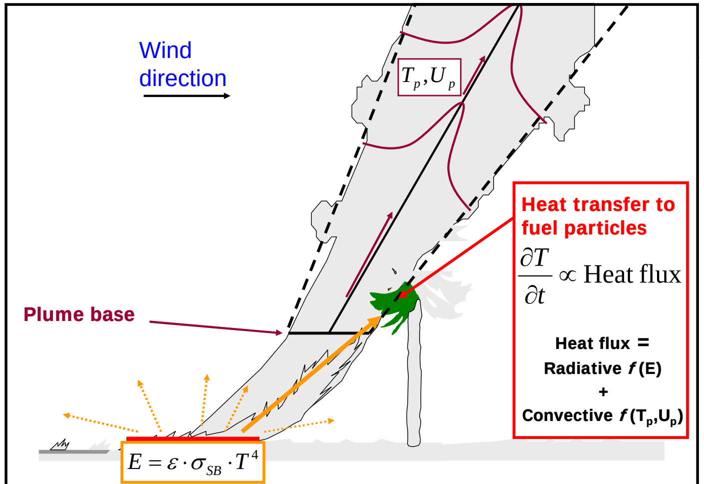


Advantages of backtracking method

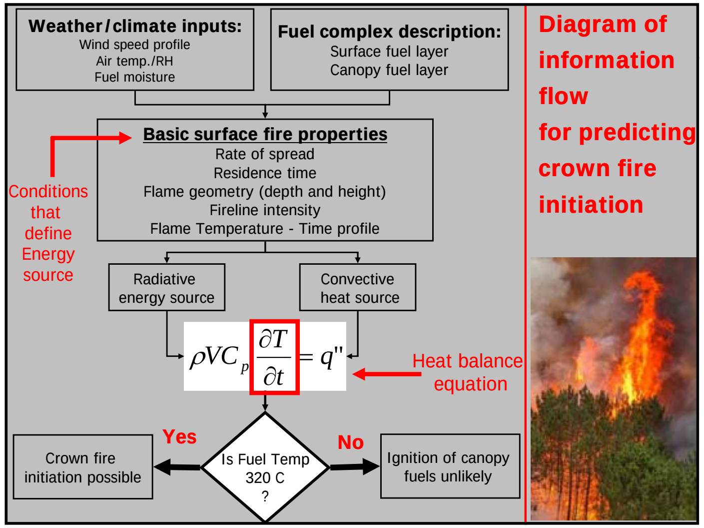
- Use well tested functional relationships;
- Requires limited amount of data;
- Avoids limitations in dataset (multicollinearity);
- Avoid some of the limitations of the fire spread model, e.g., sensitivity to fuel bed compactness.

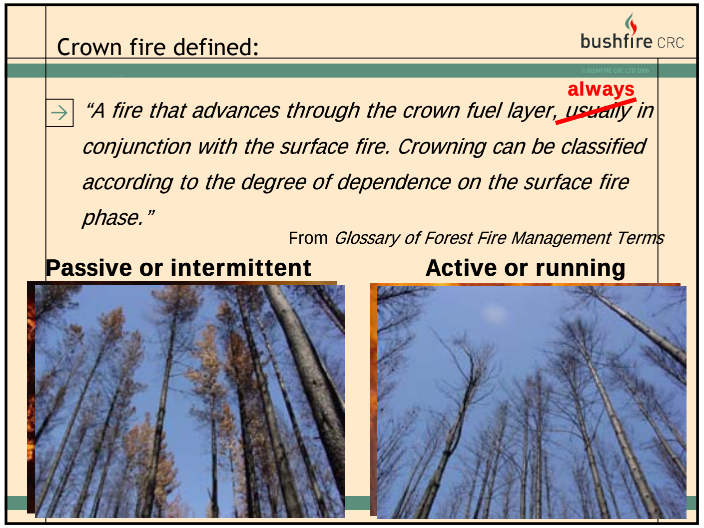


Cross section of a wind-driven surface fire



Crown fuel ignition model: idealization




Crown fire defined:
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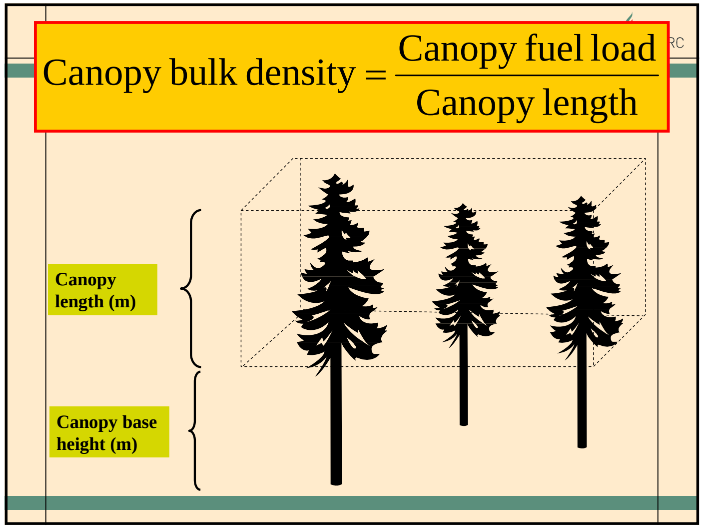
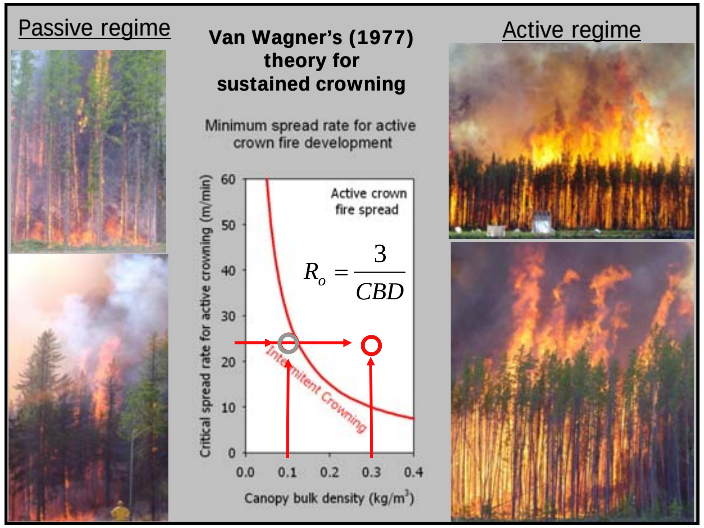
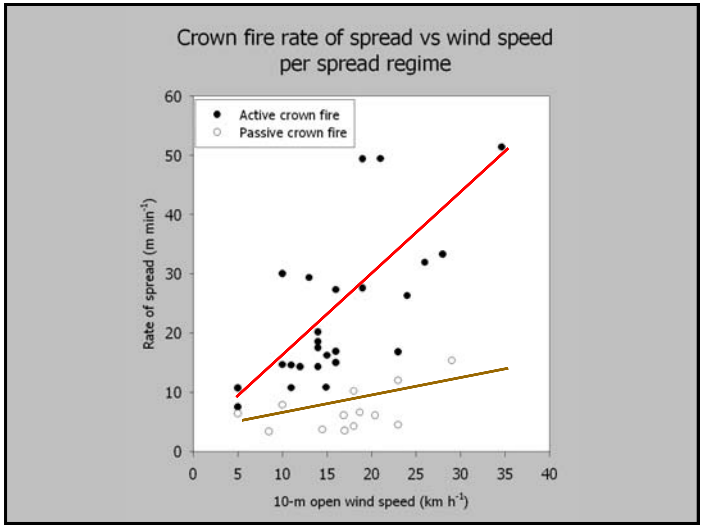
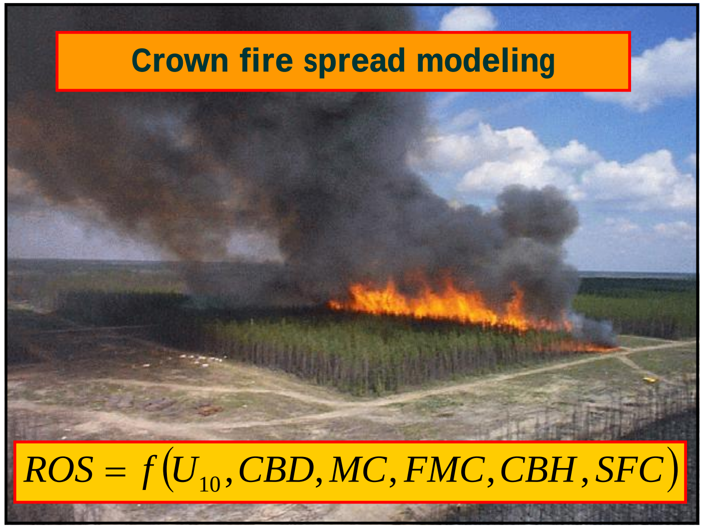
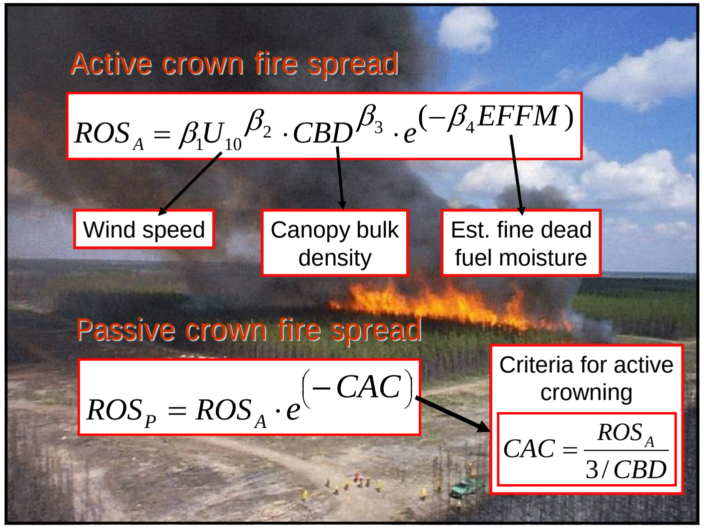
"A fire that advances through the crown fuel layer, usually in conjunction with the surface fire. Crowning can be classified according to the degree of dependence on the surface fire phase."
always
From Glossary of Forest Fire Management Terms
Passive or intermittent
Active or running

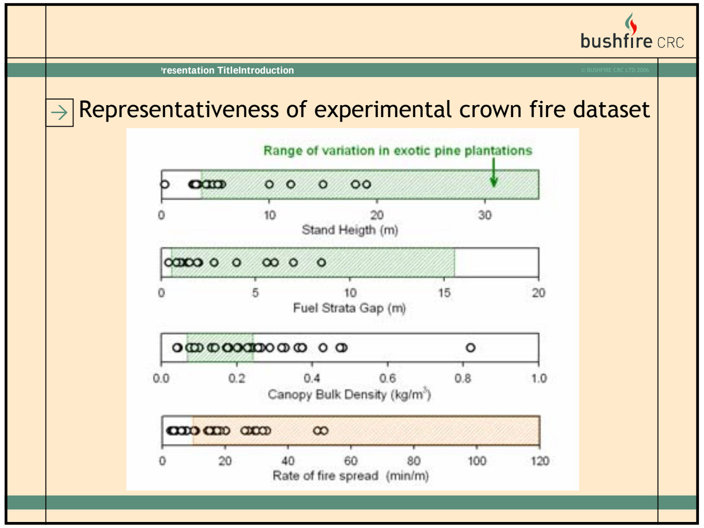

Canopy bulk density = Canopy fuel load / Canopy length
Canopy length (m)
Canopy base height (m)


Passive regime
Van Wagner's (1977) theory for sustained crowning
Active regime
Minimum spread rate for active crown fire development
Active crown fire spread
R_o = 3 / CBD
Intermittent Crowning
Critical spread rate for active crowning (m/min)
Canopy bulk density (kg/m3)
0.0 0.1 0.2 0.3 0.4
0 10 20 30 40 50 60


Crown fire rate of spread vs wind speed per spread regime
Active crown fire
Passive crown fire
Rate of spread (m min-1)
10-m open wind speed (km h-1)
0 5 10 15 20 25 30 35 40
0 10 20 30 40 50 60


Crown fire spread modeling
$ROS = f\left(U_{10}, CBD, MC, FMC, CBH, SFC\right)$


Active crown fire spread
$ROS_A = \beta_1 U_{10}^{\beta_2} \cdot CBD^{\beta_3} \cdot e^{(-\beta_4 EFFM)}$
Wind speed
Canopy bulk density
Est. fine dead fuel moisture
Passive crown fire spread
$ROS_P = ROS_A \cdot e^{(-CAC)}$
Criteria for active crowning
$CAC = \frac{ROS_A}{3/CBD}$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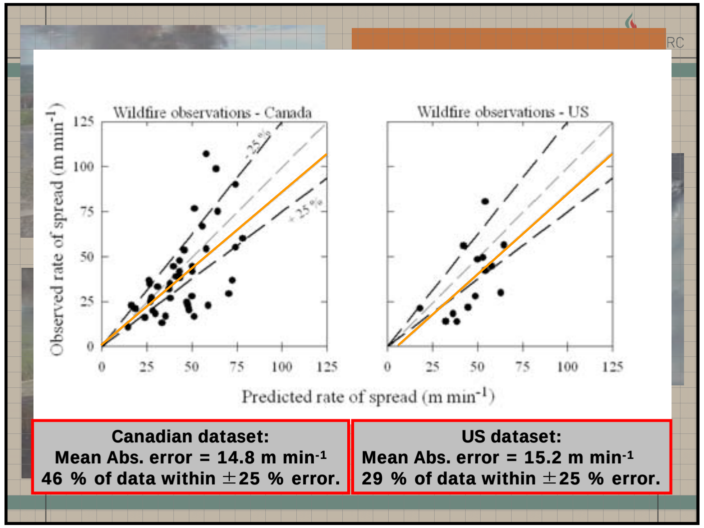
Representativeness of experimental crown fire dataset
Range of variation in exotic pine plantations
Stand Heigth (m)
Fuel Strata Gap (m)
Canopy Bulk Density (kg/m³)
Rate of fire spread (min/m)


Wildfire observations - Canada
Wildfire observations - US
Observed rate of spread (m min⁻¹)
Predicted rate of spread (m min⁻¹)
Canadian dataset:
Mean Abs. error = 14.8 m min⁻¹
46 % of data within ±25 % error.
US dataset:
Mean Abs. error = 15.2 m min⁻¹
29 % of data within ±25 % error.

Some Unsolved / Unresolved Issues

- Vertical wind profile / dead fuel moisture dynamics?
- What's the impact of stand structure changes on the fire weather environment?
- Effect of Foliar Moisture Content, Canopy Base Height and Surface Fuel Load on crown fire spread?
- Heterogeneous burning conditions: effect of transient wind on the process of crown fire initiation?

References on fire in exotic pine plantation

- Longford Fire / Wandilo Fire – Alan McArthur;
- Gnangara Fire, WA – Neil Burrows;
- Marty's Alexander PhD thesis;
- Pine synopsis (FFMG, 2007);
- 2006 Billo Road Fire – Bushfire CRC report.

OPERATIONAL APPLICATION OF SIMULATION MODELLING

Mark Finney
Fire Behavior Project, Fire Sciences Laboratory
USDA Forest Service

APPLICATION OF FIRE BEHAVIOUR MODELLING FOR RISK MANAGEMENT

Kevin Tolhurst
School of Forest and Ecosystem Science
University of Melbourne

BUSHFIRE CRC FIRE SIMULATION MODEL

George Milne and Paul Johnston
School of Computer Science and Software Engineering
The University of Western Australia
Perth, WA

Abstract:

Bushfire spread is essentially spatial and time-varying in nature. A bushfire spread simulator takes as inputs the following: the current position of the fire, the spatial variation of fuel types and slope, the temporal variation of fuel moisture and weather conditions and fire suppression activities. Fire simulation is a mathematical and computational task that applies existing fire behaviour models to the input data and projects the fire position forward through time.

The original Bushfire CRC simulator was based on the transfer of discrete packets of heat across the landscape. The landscape was divided into irregular polygons to avoid introducing directional bias via the simulation method. The simulator has been re-implemented using the contemporary programming language, Java, because of its excellent resources for developing graphical user interfaces and platform independence, while also having strong numerical capabilities. The Mk 2 simulator has kept the irregular polygonal shaped cells but, instead of the heat transfer method, adopts the more traditional propagation delay approach to simulate the spread of fire. The advantage of this approach is that fire behaviour models plug directly into the simulation engine and there is no calibration step required and therefore the simulator produces the same rate of spread as the fire behaviour meter.

The most important result from the re-development of the simulator is its extreme efficiency. Simulations that previously required several minutes to run now complete in less than a second. This quantum leap in performance will allow us to rapidly perform hundreds of simulation experiments of the same fire with different input data to factor in uncertainties in forecast weather, fuel state and the current state of a fire.

Suggested reading:

See publications in ftp site

PROGRAM A

BUSHFIRECRC FIRE SIMULATION MODEL

P.J. Johnston, G. J. Milne, J. K. Kelso
School of Computer Science and Software Engineering, University of Western Australia, WA

CRC AUSTRALIA | The University of Western Australia | School of Computer Science and Software Engineering | Department of Environment and Conservation

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Outline

1. Bushfire simulation
2. Cell versus fire line propagation
3. Efficiency of the discrete event approach
4. The Mt Cooke fire and simulations
5. Demonstration of simulator

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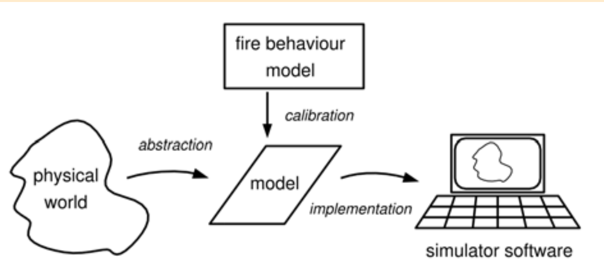
Bushfire simulation - components



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Cell based simulation	Fire line propagation
Both methods are valid	
Landscape is divided into small pieces, usually of equal area that represent the fuel, topography and fire state (unburnt, burning or burnt) through time.	The position of the burning front is propagated through time.
Cell approach has traditionally had difficulty producing realistic fire shapes.	Fire line propagation can be inefficient because of the need to propagate the entire fire front at regular short intervals.
	Complex algorithms are required for handling the situation where different parts of the fire front converge.

PROGRAM A : BushfireCRC Fire Simulation Model

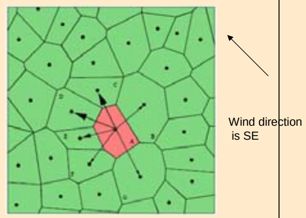
Irregular grids remove grid bias

- All simulation models are an abstraction of the physical world
- Regular grids have traditionally been used because of the ease of data import and computer programming
- Regular grids introduce bias aligned with the grid orientation which is the same everywhere.
- Irregular grids also introduce bias but the bias is different at each location and over a moderate sized region, cancel out.
- A more sophisticated computational model is required to implement irregular grids.

PROGRAM A : BushfireCRC Fire Simulation Model

Fire spread by propagation delay

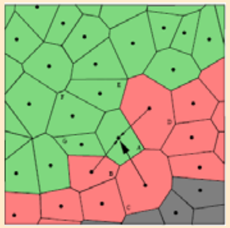
1. Each cell/patch has approximately 6 neighbours
2. When a patch is ignited, the patch's fuel type, moisture, wind speed and direction and the appropriate fire behaviour model are used to calculate the head fire rate of spread
3. The distance and direction to each neighbour determine the time it takes to ignite each neighbour from the current patch.



PROGRAM A : BushfireCRC Fire Simulation Model

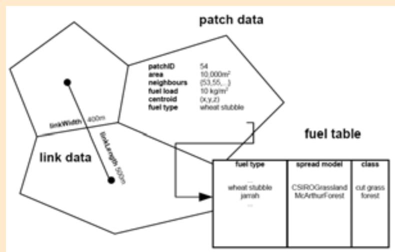
Patch states

1. At any given time, each patch is in one of the three states: unburnt, burning or burnt.
2. Ignition changes the state of unburnt patches that contain fuel to burning (e.g. a patch that contains only water remains unburnt).
3. When a patch is ignited, ignition of each of its unburnt neighbours is scheduled.
4. A patch remains burning from the time of ignition for a period equal to the diameter of the patch divided by the rate of spread.
5. Burnt cells can not be re-ignited.



PROGRAM A : BushfireCRC Fire Simulation Model

Each patch has
- location
- fuel characteristics (static)
- fuel moisture (dynamic)
- neighbour list (distance & direction)



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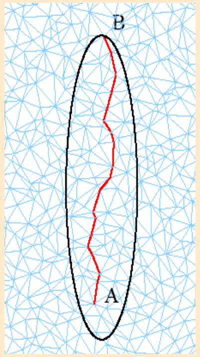
PROGRAM A : BushfireCRC Fire Simulation Model

Inter-patch spread rate



- The patch network can also be represented by the patch centre and lines connecting neighbours.
- The macroscopic rate of spread from A to B is the distance divided by the time between ignition
- For the irregular grid, the ignitions occur sequentially along the red path which is longer than the distance between A and B
- Also, segments of the path deviate from the maximum spread direction by up to 30 degrees
- Therefore to obtain the correct macroscopic rate of spread, the microscopic or inter-patch spread rate should be greater than the macroscopic rate of spread (i.e. head fire rate of spread) up to 30 degrees away from the maximum spread direction.

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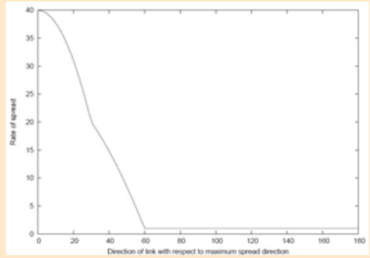
PROGRAM A : BushfireCRC Fire Simulation Model

Example function of inter-patch ROS versus direction when the head fire ROS is 20 times the zero-wind ROS

- Function derived by experimentation to derive the correct length to breadth ratio of fire spread
- Depends mostly on grid geometry and the ratio of head fire rate of spread to backing fire ROS



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PROGRAM A : BushfireCRC Fire Simulation Model

Efficiency

1. The BushfireCRC fire simulator is a *Discrete Event Simulator*
2. Instead of propagating the entire fire front at given time steps, the ignition of each patch occurs in a time-ordered sequence.
3. The number of ignition events for a simulation is proportional to the number of patches involved regardless of the fuel or weather
4. A fire front simulator advances the entire fire front at each time step. The time step must be chosen small enough that the fastest moving part of the fire is accurately modelled. Rates of spread can vary by a factor of at least 100 (e.g. head fire versus backing fire), so much of the fire front is advanced in many small steps when a single step should suffice.
5. A fire front simulator also needs to check for overlap of converging fire fronts, whereas the cell approach simply ignores the attempted ignition of an already burning patch.

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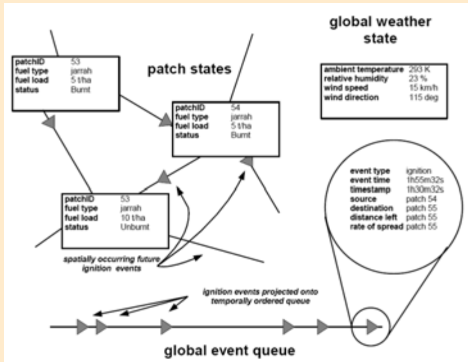
PROGRAM A : BushfireCRC Fire Simulation Model

A Discrete Event Simulator steps from event to event



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PROGRAM A : BushfireCRC Fire Simulation Model

Mt Cook Fire, WA, 9-11 January 2003 (courtesy of Department of Environment and Conservation, WA)

Details on Fire Conditions and Fire Behaviour

1. Origin - Lightning strike at about 9:50 pm on 9th January 2003 on top of steep rocky hill top, 1km south of Millars Log Road

2. About 30 Hectares burnt in about 6 hours overnight within steep, and inaccessible terrain. Rate of Spread about 80 m/hr with 3 - 4 metre flames.

3. Fire rapidly accelerates after 8:00am driven by hot, dry NW winds 30 Km/hr. Rate of Spread ranges from 500-1000 m/hr burning in 15 year old fuels.

4. Fire crosses power line at 12:20 pm on 10th January 2003, moving at 2500 m/hr, 15-25 metre flames, and spotting about 1-2km ahead of main fire. Air temperature 35 , Minimum Relative Humidity 20%, Fuel Moisture 3%.

5. Complete defoliation resulting from fire intensity of about 75,000 kw/hr in 17 year old Jarrah fuels.

6. New fire resulting from spot fire about 6 km downwind from main head fire.

7. Fire intensity reduced from 75,000 to about 15,000 kW/hr as fire moves out of 17 year old into 7 year old fuels. Note the reduced level of defoliation & scorch evident on satellite image.

8. Spot fires blown into the 3 year old patchy prescribed burn were allowed to burn out to tracks at low intensity.

9. Fire driven by westerly winds moves from 10 year old fuels into 23 year old fuels with a subsequent increase in fire intensity.

10. At 5:00am on 11 January 2003, headfire (10 m flame height) runs into 5 year old fuels and is dramatically reduced in intensity and rate of speed. Ground forces undertake successful direct attack on headfire.

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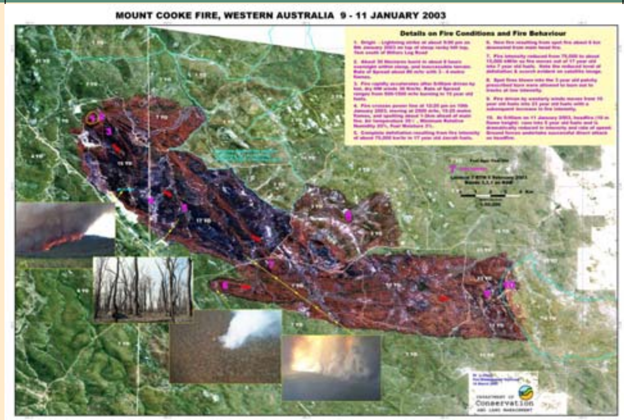
PROGRAM A : BushfireCRC Fire Simulation Model



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PROGRAM A : BushfireCRC Fire Simulation Model

Simulation of Mt Cooke fire: Input data

- Northern Jarrah fuel type with fuel loads calculated from time since previous fire (Red book)
- Surface Moisture Content versus time (calculations by L. McCaw, DEC)
- Wind speed versus time from weather station away from fire ground multiplied by a single scale factor
- Wind direction inferred from fire shape.
- Ignition at 4 am 10 Jan, plus spot fire at 12 noon
- Topography

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Simulation with observed wind speed x 1.25

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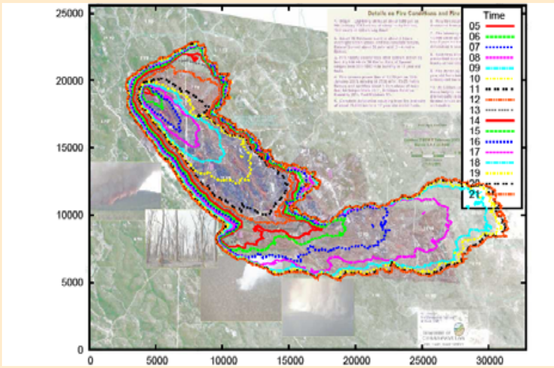
Simulation with observed wind speed x 1.3



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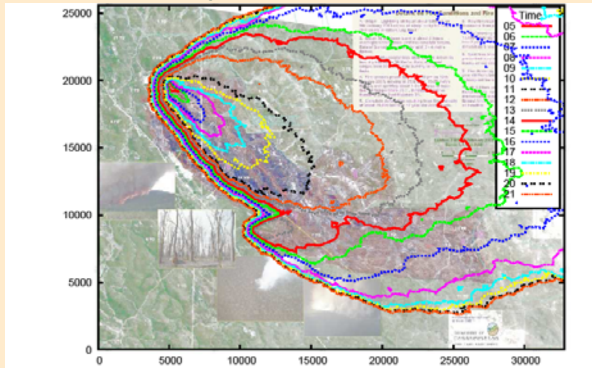
Simulation with observed wind speed x 1.3, and all fuel 15 years old



PROGRAM A : BushfireCRC Fire Simulation Model

Lessons learnt from simulation of Mt Cooke fire

- Each simulation took around 1 second to run for patches of approx. 250 m diameter
- A small increase in wind speed causes a large increase in area burnt
- Reduced fuel load due to prescribed burns contained the fire on the northern flank
- The BushfireCRC simulator reproduces fire spread with slight modification of input data
- Red book possibly under-predicted ROS for this fire?

PROGRAM A : BushfireCRC Fire Simulation Model

Conclusions

1. Simulator is very fast
2. Initial validation is promising
3. Rapid simulation allows us to consider applications involving multiple simulations allowing for the uncertainty in the input data (forecast weather, fuel moisture model, fire behaviour model, probabilistic spotting model)
4. Further development required on user interface, data import, inclusion of spot fire model

NATIONAL FIRE BEHAVIOUR PREDICTION SYSTEM

Jim Gould and Miguel Cruz
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Abstract:

Fire behaviour prediction is a combination of quantitative and qualitative information based on experience and scientific principles of describing the combustion and behaviour of fire influence by topography, weather and fuel, and the recognition of conditions that lead to extreme fire behaviour. Predictions are based on mathematical models that integrate important factors in a consistent way. Fire behaviour prediction is much more that use of a model to do the calculations. The process also includes determining the proper inputs for the calculations and interpreting the results for the application in hand. The National Fire Behaviour Prediction (NFBP) system will consist of four primary components (fuel models, fuel moisture models, wind models, and fire behaviour models) to predict fire characteristics (i.e. rate of spread, flame height, fireline intensity, onset of crowning spotting potential, etc). The NFBP system components will be available in different forms, from circular slide rules and tables to a simulation model aimed at forecast fire growth and behaviour over complex terrain, through variable fuel and changing weather conditions. The desired accomplishments of the proposed National Fire Behaviour Prediction Systems is to provide fire managers with better operating models to implement prescribed burning programs, suppression resources, risk and biodiversity management programs.

PROGRAM A

NATIONAL BUSHFIRE BEHAVIOUR KNOWLEDGE System

a suite of fire behaviour tools to support fire management decision making

Jim Gould & Miguel Cruz
Ensis Biosecurity and Protection
Bushfire Research (CSRIO)

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Fire behaviour

1. Predicting fire behaviour of fires is an essential activity for managing bushfires:
   a) Know how fast a fire will spread
   b) Planning and executing fire fighting control efforts
   c) Essential to fire fight safety
   d) Community protection, safety and warnings
   e) Planning and conducting prescribed fire

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Understanding fire behaviour

Essential to situational awareness for all levels of a fire management team -

- the front line fire fighter who needs to identify local hazardous conditions,
- the incident commander who is charged with looking out for the safety of fire fighters and the general public.

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Existing fire behaviour models-

each mathematically calculates fire behaviour from weather, fuel and topography information

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Existing models formats

1. Equations- all
   a. Incorporated into spread sheets (e.g. Buttongrass moorland)
2. Meters- circular slide rulers
   a. McArthur grassland and forest fire danger meters
   b. CSIRO Grassland fire behaviour meters
3. Tables
   a. Forest Fire Behaviour Tables for Western Australia
   b. Buttongrass Moorland (Tasmania)

1. Field guides
   a. Overall fuel hazard guides- e.g. Victoria and SA
   b. Field guide for fuel assessment and fire behaviour prediction for dry eucalypt forest (Proposed production by Ensis and DEC WA).
2. Charts and nomograms
   a. Control burning in eucalypt forest- McArthur Leaflet 80
   b. Prescribed burning guide for young regrowth forests - Cheney Gould &Knight 1992
3. Computer programs
   a. CSIRO fire calculator
   b. Phoenix Bushfire Risk Modelling (Tolhurst, Uni Mel)
   c. Bushfire CRC fire simulation model (Milne & Johnston, UWA)

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National Bushfire Behaviour Knowledge System

(NBBK System)

1. Is not another fire behaviour model
2. Proposed development of a fire behaviour knowledge system-
   a) Include existing and future fire behaviour models
   b) Allows practitioners to view and compare existing fire behaviour observation directly
   c) Data richness of experimental and field observations
   d) Links to case studies

National Bushfire Behaviour Knowledge System

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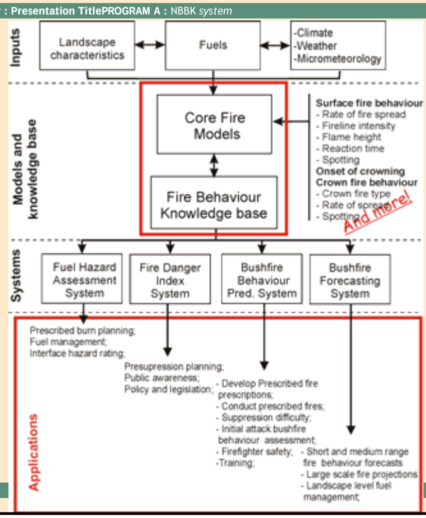

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Several modules

1. Fuel hazard assessment system
2. Fire danger rating system
3. Fire behaviour prediction system
4. Bushfire forecasting system

The system will be available in different formats from circular slide rules, charts, tables for use in the field to scaled up to decision support systems

Bushfire Behaviour Prediction System

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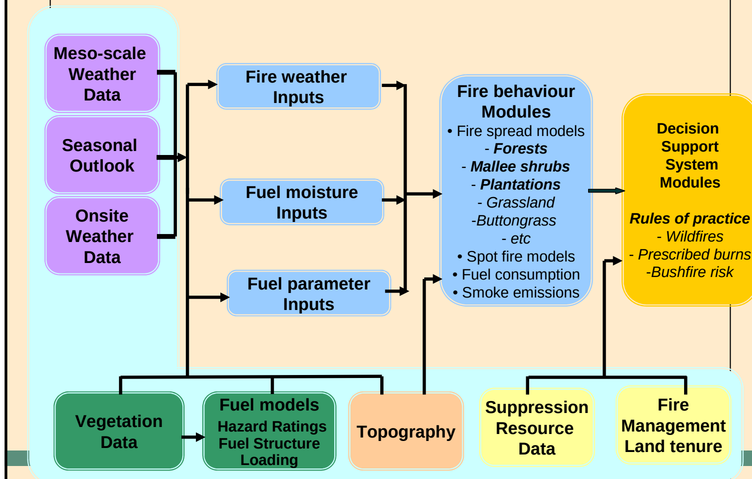

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Summary

rethinking approach to fire behaviour

1. A fresh look at fire behaviour knowledge with a more integrated view of fuel, weather and fire behaviour.
2. More efficient in providing better information for protecting life, property and the environment.

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Summary

meeting the challenge

1. Conceptual framework for bushfire behaviour knowledge system:
   a) Suite of fire behaviour tools to support fire management
   b) Searchable fuel and fire behaviour models
   c) Databases- fuel, weather, topography, fire behaviour, etc
   d) Case studies
2. Need for communication and collaboration among researchers and end users.

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Outcome:

Proposed National Bushfire Behaviour Knowledge System (NBBK System):

➢ *To provide fire managers with better operating models to implement prescribed burning programs, suppression resources, risk and biodiversity management programs*


Thank You
Acknowledgements:
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