Towards the next generation of operational fire spread models

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16 May 2012
Overview

• What is an operation fire spread tool?
• 1st generation fire spread tools
• 2nd generation fire spread tools
• Do we need anything more?
• What should be in a next generation fire spread tool?
• The CSIRO Pyrotron research facility
• Summary
Operational fire spread models

- Tool used by fire management personnel to predict the behaviour of a fire
- Intended to provide information on fire behaviour for variety of purposes:
  - Preparedness
  - Suppression planning and attack
  - Warnings
  - Application of fire (prescribed burning)
- Require easily acquired inputs
  - Easy to use in the field
- Produce useful outputs
  - Predict potential fire behavior—speed of fire front/rate of area/perimeter increase
1\textsuperscript{st} generation fire spread models

- 1950s-60s:
  - Derived from observation of experimental and wildfires.
  - Rudimentary statistical analysis, simple functional forms:
    - McArthur, Burning Guide for Dry Eucalypt Forest
    - Peet, Forest Fire Danger Tables (WA)
    - McArthur, Forest Fire Danger Meter Mks 2-4
    - McArthur, Grassland Fire Danger Meter Mks 1-3
1st generation fire spread models

• 1970s-80s:
  • No major modifications to existing systems
  • Metrication
    – McArthur, Mk 5 Forest Fire Danger Meter
    – McArthur, Mk 4-5 Grassland Fire Danger Meter
    – Sneeujagt and Peet, Forest Fire Behaviour Tables for WA
Alan McArthur : 1953 - 1978

- First full-time bushfire research in Australia
- Developed a robust methodology for the empirical study of bushfires
- Conducted over 1200 experimental fires in a variety of vegetation:
  - Grasslands
  - Eucalypt forests
  - Pine plantations
- Mostly small (< 1 ha, < 60 mins)
- Augmented with observations of wildfires
2nd generation fire spread models

• 1990s-2000s
  • Driven by improved data analysis techniques
  • Primarily new understanding of fire:
    – Threshold winds to drive fire forward
    – Bigger fires spread faster than smaller fires
• CSIRO Grassland Fire Spread Meter
• Dry Eucalypt Forest Fire Model (Vesta)
• Mallee-heath model
• Button-grass moorland, heath
Australian Bushfire Behaviour Research: A short history

The CSIRO Pyrotron: Future fire now
2nd generation fire spread models

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Effect of headfire width
Threshold winds and wind function

![Graph showing the rate of spread in kilometers per hour (km h⁻¹) as a function of wind speed in kilometers per hour (km h⁻¹) for different conditions: Natural/ungrazed, Grazed/mown, and Eaten-out. The graph exhibits a clear trend where the rate of spread increases with wind speed. The natural/ungrazed condition shows the highest rate of spread at higher wind speeds, followed by the grazed/mown condition, and the eaten-out condition shows the lowest rate of spread.]
Why do we need anything more?

• Is there a need for a next generation fire spread model?
  • They do a pretty good job
  • Good match for level of sophistication of agencies
  • Provide ability, within suitable framework, to simulate fire spread over the landscape in much faster than real time: e.g Phoenix, Australis.

• However...
  • They are designed to predict mean values only (periods > 20 min) for flat ground and homogenous conditions—no dynamics
  • They can’t be used with confidence outside the range of conditions used to develop them.
  • Can’t tell us anything about the whys of fire behaviour
    – Headfire width?
    – Wind speed
    – Slope
Why do we need anything more? (cont)

• They can’t be modified or extended without changing the whole model.
• They are deterministic and tell us nothing about the uncertainty in model performance (not just uncertainty in input values)
What should be in a 3rd Gen model?

• Need to capture more of the physical processes involved in propagation of bushfires:
  • Biophysical structure and chemistry of fuel
  • Thermal degradation and combustion processes of fuels
    – Heat release
    – Species (for emissions)
  • Heat transfer to unburnt fuels
    – Ignition problem
    – Wind, slope
    – Turbulent interactions (ABL, topography, vegetation, fire)

• Needs to be parsimonious
  • Only include minimum inputs to ensure workable results for operational use
  • Faster than real time??

• None of this is new
Cellulosic combustion pathways

\[ S \xrightarrow{k_1} V \xrightarrow{k_3} \text{Products} + \Delta \]

\[ S \xrightarrow{k_2} C \xrightarrow{k_4} \text{Products} + \Delta \]

\[ V + O_2 \]
The CSIRO Pyrotron

- 25-m long combustion wind tunnel located at Yarralumla, ACT.
- Designed to study the combustion of bushfire fuels under repeatable conditions.
- Design informed by experience with field experiments.
- Cannot replicate the behaviour of a bushfire.
- Intended for the study of the mechanisms and processes involved in the propagation of fire through bushfire fuels.
The CSIRO Pyrotron

- Much of the tunnel exists to remove turbulence.
- Air flow improvements aim for variation < 10%.
- Designed for study of combustion of forest litter fuel (up to ~2.5 kg m⁻¹).
- Can be used to study combustion of other fuels such as grasses, short shrubs, small logs, etc.
- Fuel can be prepared in oven to achieve required fuel moisture content or allowed to vary with ambient conditions.
- Intended as a national facility, available for general use
Air flow characterisation: Uniformity

0.1 Hz contours of percentage difference from mean air flow at a fan speed of 325 rpm.

- mean variation < 3% of mean air speed.
- similar form to turbulence kinetic energy ($\frac{1}{2}v'^2$)
3rd Generation Fire Spread Models | Andrew Sullivan
Summary

• Operational tools are used on the ground for range of purposes
  • Utilise small number of “easily” obtained inputs
  • Simple technological delivery of outputs
  • Provide useful results of mean behaviour
  • Deterministic, no information on uncertainty
  • No understanding of fire behaviour
  • Limited to conditions used to develop them

• Need for improvements?
  • Uncertainty and probabilistic outputs
  • Wider range of applicability (weather, fuel, terrain), particularly under more extreme conditions

• Can we include more physical aspects in operational tools and keep it useable?
  • Complex model simplification? Simple model complication? Hybrid model?
Thank you

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