FIRE COALESCENCE AND MASS SPOTFIRE DYNAMICS: EXPERIMENTATION, MODELLING AND SIMULATION

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EXTREME & DYNAMIC FIRE SPREAD

- As noted at a recent international conference(!), there is a *change in the air* with regards to fire behaviour science...

- A number of recent developments have shed new light on the propagation of wildfires - a number of these involve extreme and dynamic effects.

- Australia is well-positioned to play a leading role in these developments!

The quasi-steady assumption and dynamic fire spread.

Rate of spread = a function of (W, D, T, H, U, S, ...)

W is Fuel Weight (tonnes ha^{-1})
D is Drought Factor (antecedent rainfall conditions)
T is Temperature (dry-bulb, °C)
H is Relative Humidity (%)
U is Wind Speed (average at height of 10m, km h^{-1})
S is Topographic Slope (degrees)
Etc...

The quasi-steady assumption:

Constant "environmental" conditions → Constant rate of fire spread

NO DYNAMICS!

DYNAMIC FIRE PROPAGATION

The Next Generation of Fire Behaviour Models will acknowledge and address dynamic fire spread, which arises due to:

- Fire-atmosphere(-terrain) interactions - ARC
- Fire-fire interactions
- Transitions from a radiative propagation mechanism to a convective propagation mechanism
    - Goetler vortices (cf. Finney and Forthofer),
    - Burgers-Rott vortices (e.g. VLS) - ARC
    - Plume attachment (slope and wind driven) - ARC

SPOT FIRES AND FIRE COALESCENCE

• Fire behaviour in Australian vegetation is often characterised by the occurrence of spot fires

• Spotting can be the dominant process under extreme fire conditions, and adds a considerable dynamic element to the overall propagation of fires – the resulting spread should not be considered as quasi-steady!

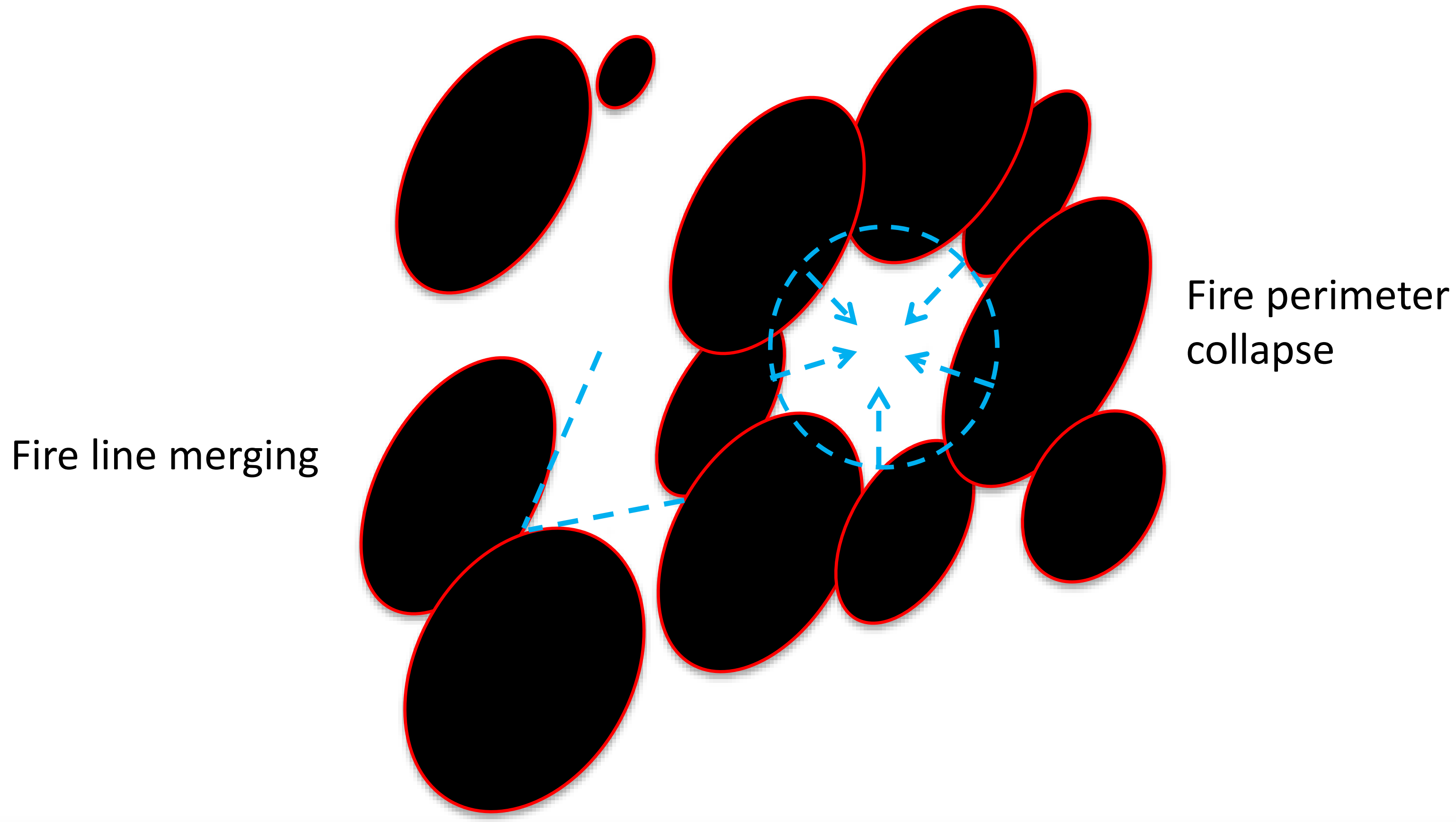
• Multiple individual fires grow and merge into larger ones – this can result in increases in fire intensity and spread!

• Such effects are currently not accounted for in operational models.....!!!

• Implications for fire power and pyro-convective budget.

SPOT FIRE COALESCENCE

How do spot fires coalesce?



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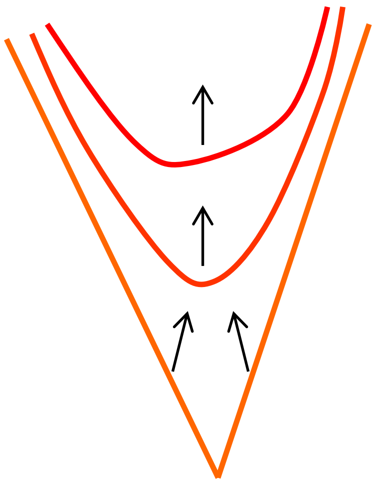
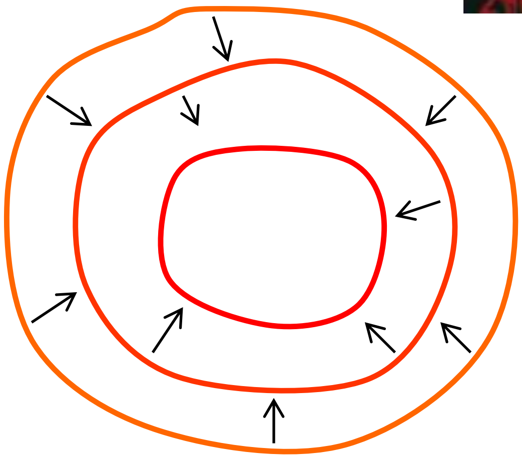


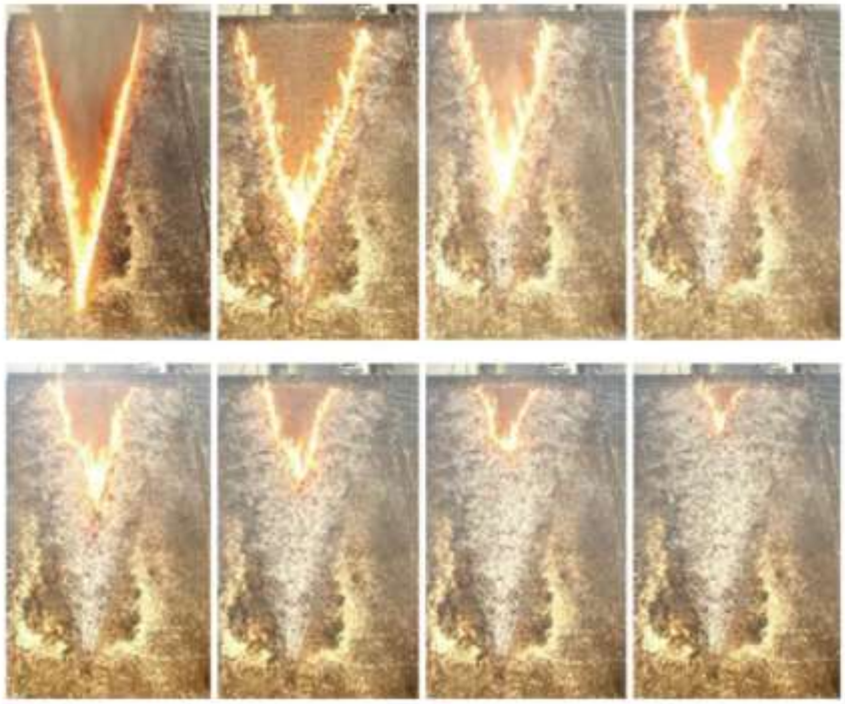
Fire line merging: Merging of two oblique lines of fire

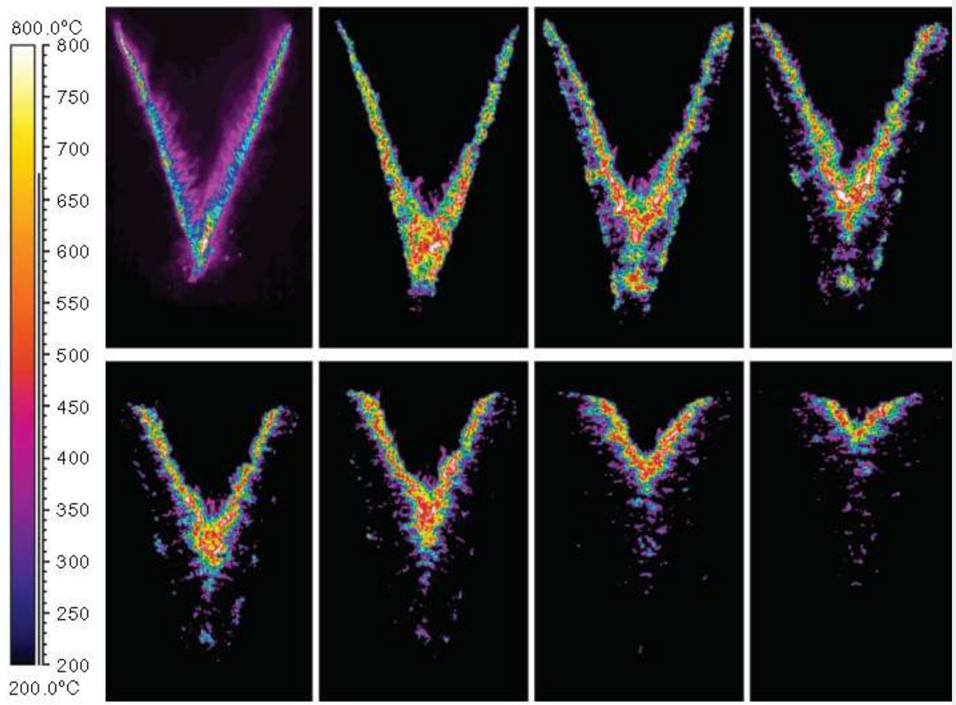


Collapse: A ‘ring’ of fire burning in on itself

DYNAMIC FIRE PROPAGATION

Fire line merging.



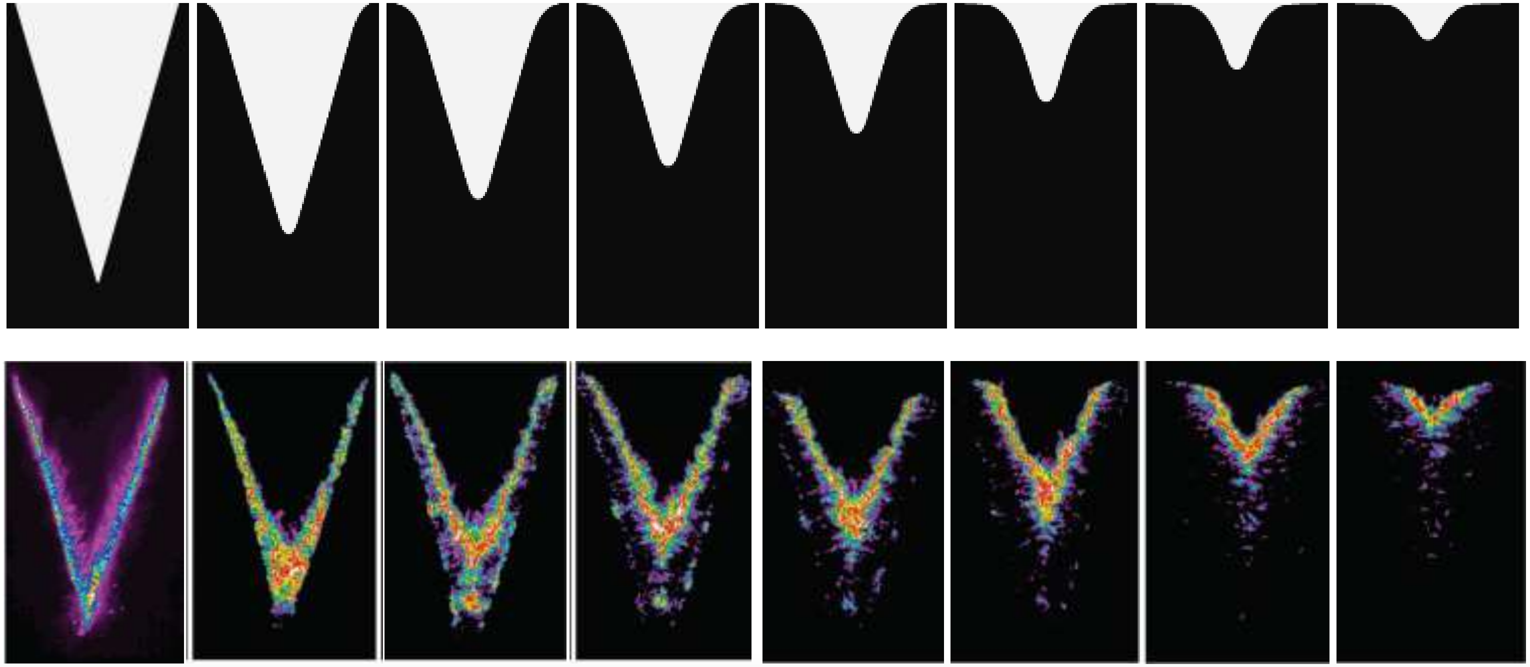


Source: Viegas et al. (2012) International Journal of Wildland Fire

DYNAMIC FIRE PROPAGATION – FIRE LINE MERGING

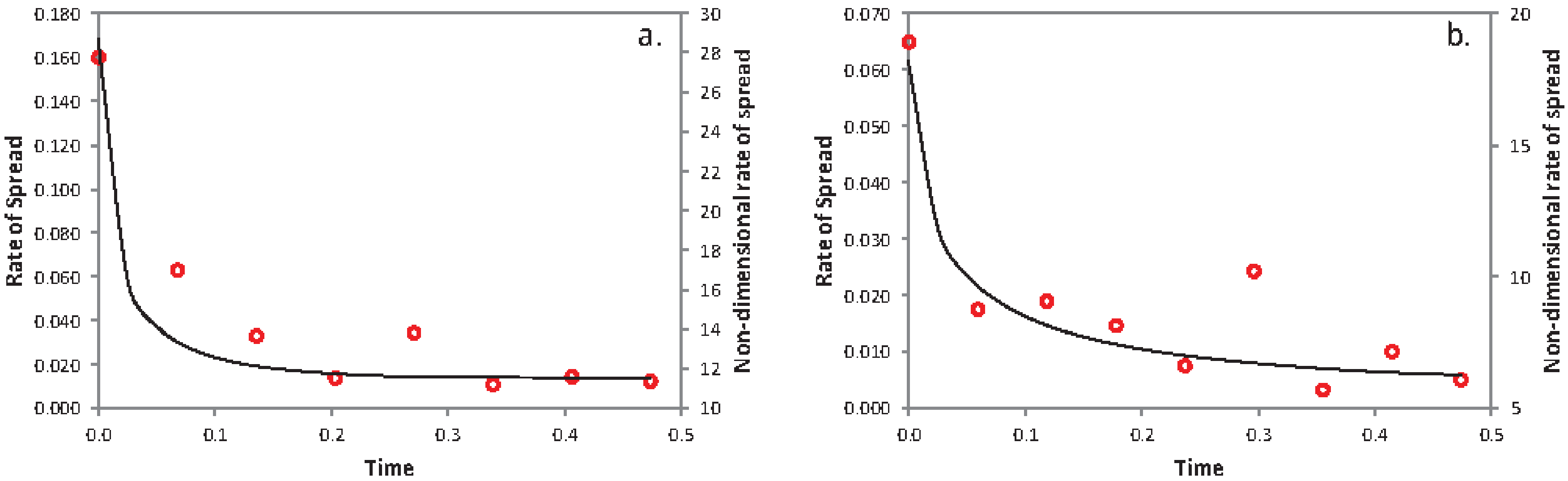
Level set methods: Modelling fire growth with a RoS that depends on fire line curvature.

$$\partial_t \phi + \alpha \nabla^2 \phi + N(\phi) = 0, \quad N(\phi) = \alpha \frac{\nabla \phi}{|\nabla \phi|} \cdot \nabla(|\nabla \phi|) + \beta |\nabla \phi|.$$



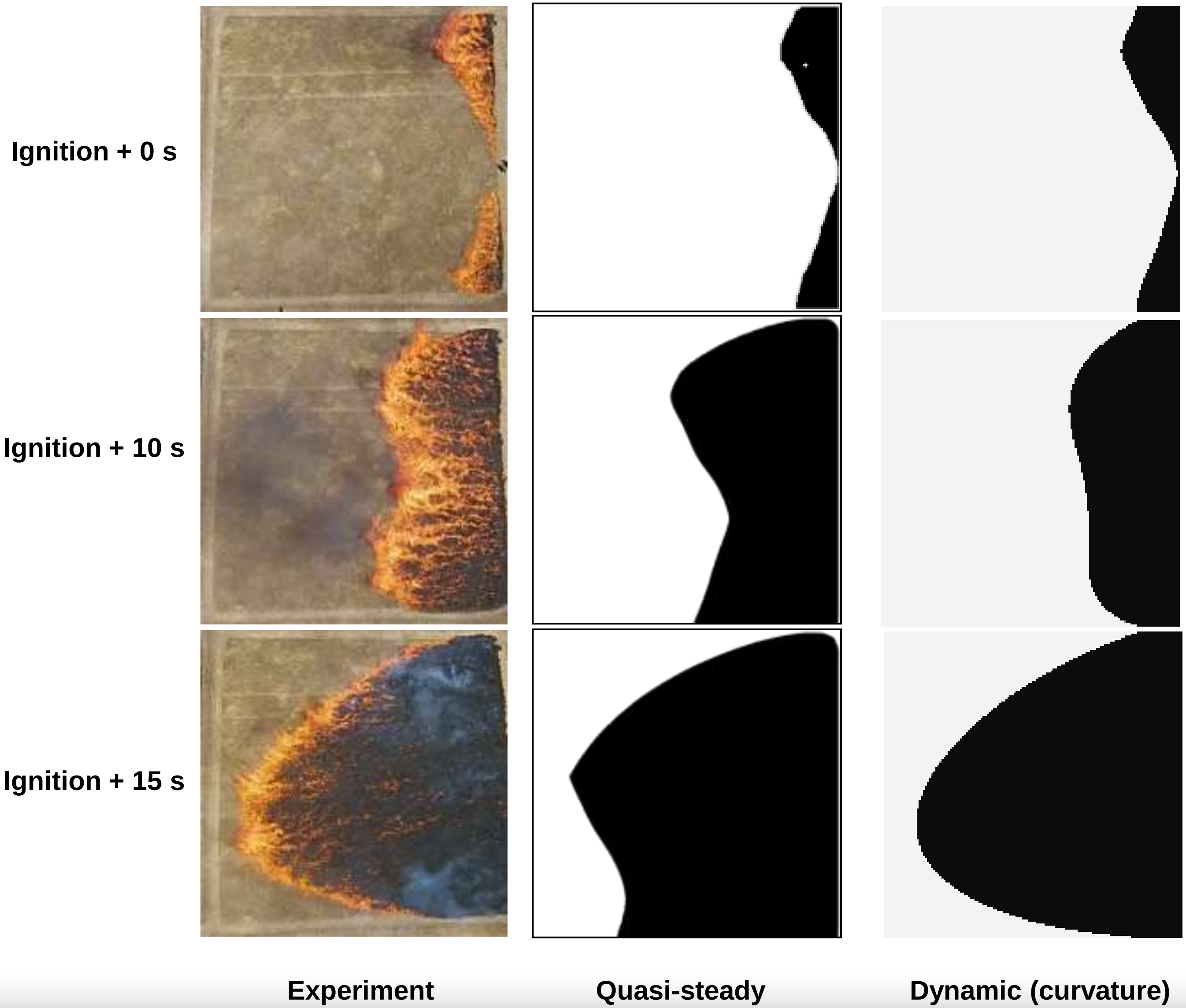
DYNAMIC FIRE PROPAGATION – FIRE LINE MERGING

Initial results indicate that incorporating curvature does indeed capture the dynamics observed in experimental fires...



Moreover, it has shown that quasi-steady models have shortcomings even in relatively simple burning scenarios...

DYNAMIC FIRE PROPAGATION



SPOTFIRE PROJECT….

DRAFT: WORK IN PROGRESS!
Contracts yet to be signed…

RESEARCH PROJECT AIMS

1. Investigate the processes involved in spot fire formation and the coalescence of free-burning fires under experimentally controlled conditions (and simulated fires at larger scales!)

2. Quantify the physical mechanisms involved....!

3. Investigate the geometric drivers of fire line propagation (e.g. fire line curvature)

4. Development of simplified 'proxy' models that accurately reproduce some of the more complicated dynamical effects

RESEARCH PROJECT STAGES

1. Experimental investigation of dynamic fire spread
2. Dynamic modelling of fire line merging and coalescence
3. Spotting process model in simulation framework (WRF-Fire)
4. Validation and testing

RESEARCH PROJECT DELIVERABLES

- The project deliverables are couched in terms of scientific papers.

RESEARCH PROJECT DELIVERABLES

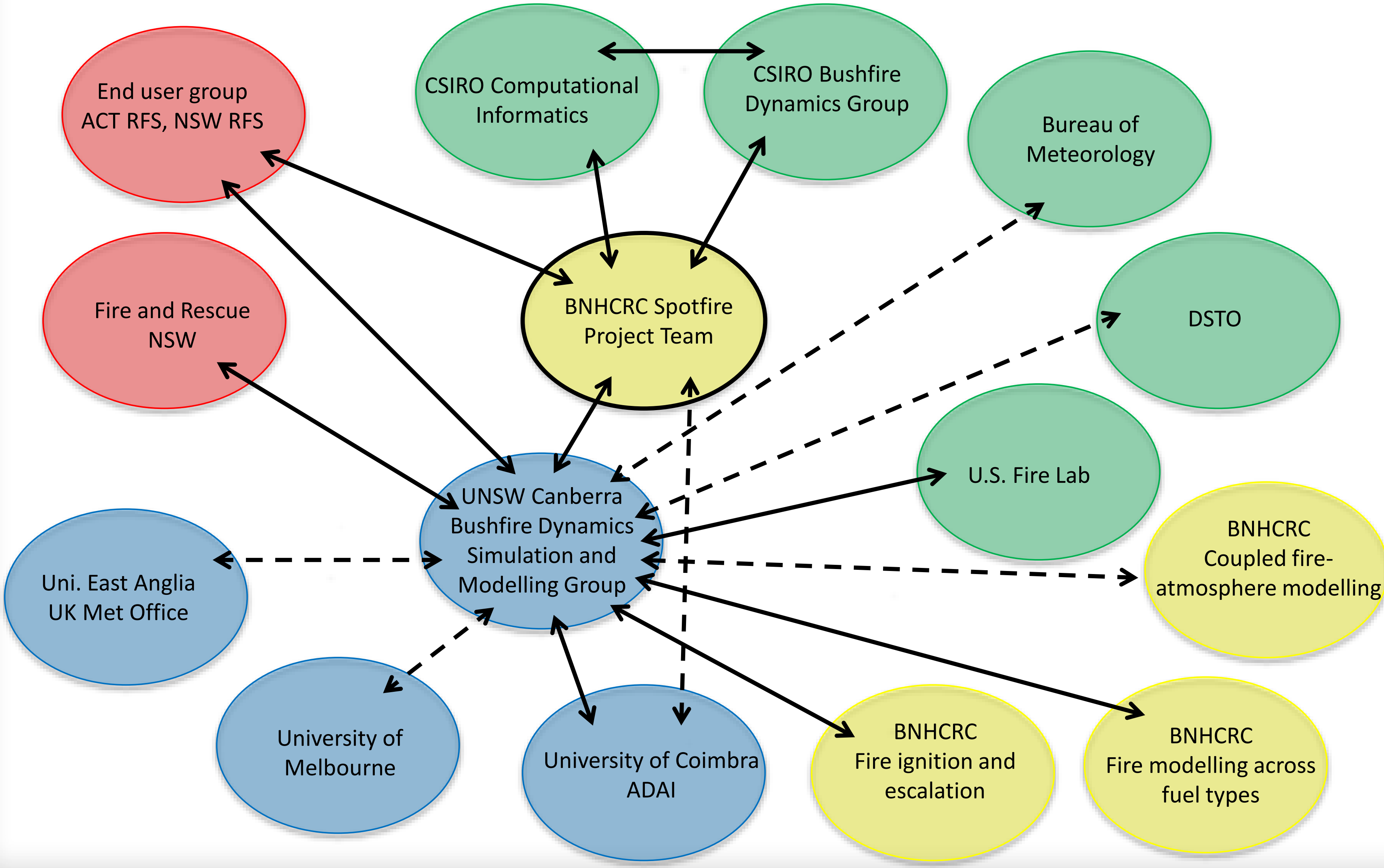
1. Simulation of fire line merging using curvature-based models
2. Simulation of wind-driven fires incorporating intrinsic dynamics
3. Mathematical formulation of a curvature dependent speed for fire spread (PhD underway)
4. Dynamic fire spread experiments (Pyrotron)
5. Spot fire coalescence experiments (Field)
6. Ember-fall distribution from an evolving heat source (PhD underway)
7. Other statistical characteristics of ember transport and ignition
8. A model for spot fire ignition and coalescence (PhD underway)
9. Amendments to the pyro-convective energy budget due to spotting effects

+ there's likely to be others...

RESEARCH PROJECT OUTCOMES

1. The papers just mentioned... Plus a model!
2. Reports aimed at the end-user audience
   - These will document model frameworks in appropriate language and at an appropriate technical level
   - These will provide guidance on the implications of the research for operational procedure
     - ❑ Intrinsic dynamics of wildfire – operational and safety implications
     - ❑ Documentation and implementation of a model for spot fire ignition and coalescence.
3. Still early days... Still in months BP! Will consult with end users....!

RESEARCH NETWORK



PROGRESS SO FAR…

1. Simulation of fire line merging using curvature-based models
    - Basic Level Set simulator has been developed and has been modified to incorporate basic curvature effects
    - The simulator has been applied to the fire line merging case
    - Collaboration with Jorge Raposo and Domingos Viegas, ADAI
    - Paper is nearly ready for submission!
2. Simulation of wind-driven fires incorporating intrinsic dynamics
    - Level set simulator has been successfully tested on ring fire cases
    - Simulator has been successfully applied to experimental burn (Ballarat) data sets
    - Paper is nearly ready for submission!
3. Mathematical formulation of a curvature dependent speed for fire spread
    - PhD student (Chris Thomas) has started at UNSW Canberra – looking at coupled fire-atmosphere modelling and how it applies to curvature dependence

THAT'S ALL!

FOR NOW…

QUESTIONS?