CHALLENGES IN PHYSICS-BASED BUSHFIRE MODELLING

PROJECT: FIRE SPREAD ACROSS FUEL TYPES

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An Australian Government Initiative

(http://eecue.com/b/1048/Station Fire 2009 Station-Fire-In-Photos.html)

PROJECT BACKGROUND

1) Emergency services managers need to be able to predict the spread of bushfires so that they can identify regions in imminent danger, and deploy fire-fighting resources
2) They use largely non-physics-based empirical models for this purpose

Mark Smith/AFP/Getty Images

RESEARCH TEAM: NEW MEMBERS

Dr Duncan Sutherland
Postdoctoral Fellow
Victoria University

Rahul Wadhwani
PhD student
Victoria University

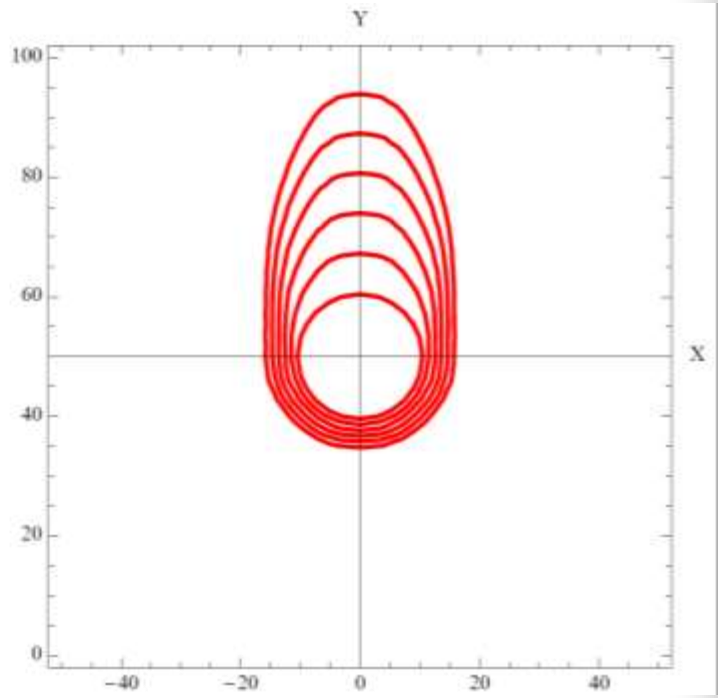
Collaborator: Dr William Mell, the US Forest Department
Two PhD students, Victoria University
One PhD student, University of Melbourne

WHAT DO WE WANT FROM A MODEL?

1) A prediction of the rate of the spread of fire and its intensity
2) The prediction must be accurate and fast
3) Forecast the path of fires ahead of real time for use in fire fighting operations
4) Assessment of risk for urban and infrastructure planning

CURRENT NON-PHYSICS BASED MODELS

1) Fire front type propagation model
2) Can be used for community and landscape scale simulation
3) Provide forecasts of fire behaviour
4) Depends on empirical data such as spread rate
5) Underestimate local weather effects and fire channeling particularly around the urban interface



Pugnet, L., et al. "Wildland–urban interface (WUI) fire modelling using PHOENIX Rapidfire: A case study in Cavaillon, France."

PHYSICS-BASED MODELLING

1) Start with fundamental equations for:
   a) Wind transport
   b) Combustion of materials and transport of gases and soot
   c) Heat transfer by radiation, conduction and convection
2) Solve a large system of equations
   a) Feasible with High-Performance Computing
3) This is time consuming but gives a more robust result than empirical models
   a) Model which accounts for the inherent, real world, uncertainties in the data
   b) Numerical robustness: solution is independent of numerical parameters such as grid resolution

WILDLAND-URBAN INTERFACE FIRE DYNAMICS SIMULATOR (WFDS)

1) Physics-based fire model developed by the National Institute of Standards and Technology (NIST), US
2) Being developed for application (end use) over three spatial scales:
   a) Laboratory: ~10m x 10m area encompassing laboratory experiments and a valuable tool for fire researchers; purely physics-based
   b) Community: ~10^2m x 10^2m area able to modelled by both physics based and non-physics based models, and
   c) Landscape : ~ 10^3m x 10^3m area (currently only a hybrid non-physics- and physics-based model)

WHAT ARE THE MAIN CHALLENGES IN PHYSICS BASED MODELLING, AND HOW CAN WE RESOLVE THEM?

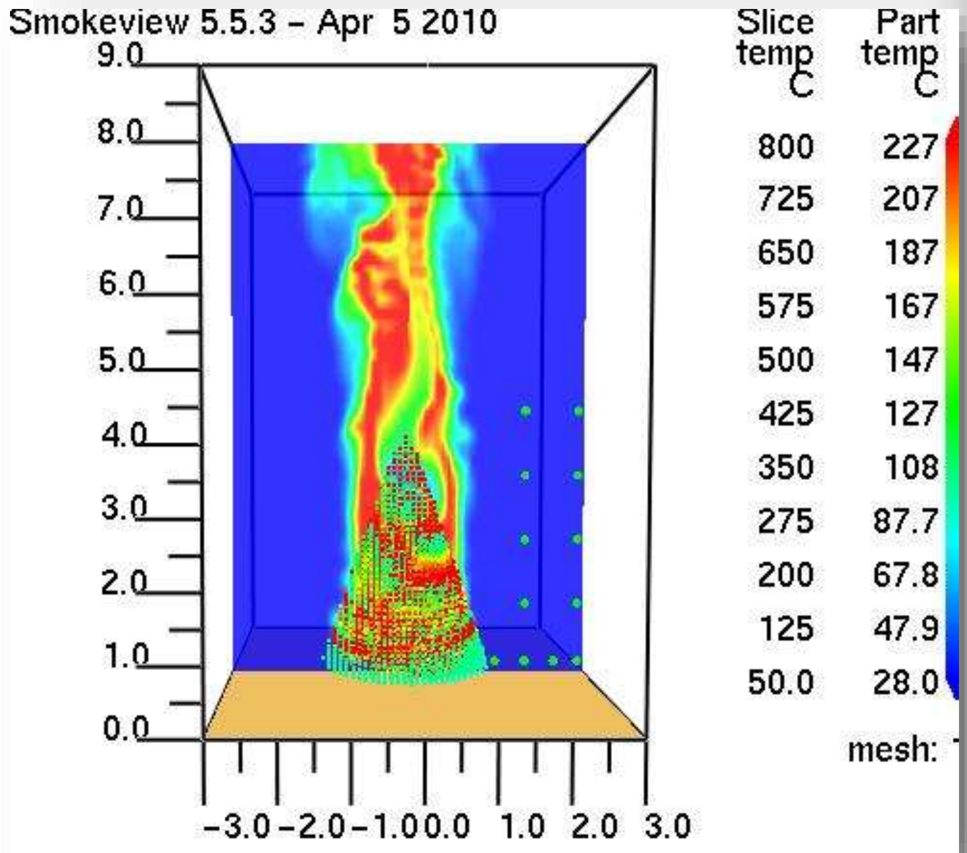
A MAJOR CHALLENGE – ACCOUNTING FOR A VERY WIDE RANGE OF LENGTH SCALES

PHYSICS-BASED MODELS: SUBMODELS

1) Physics-based models require submodels for each process considered, including:
   a) Fluid motion (Sub-sonic flow)
   b) Turbulence (Large Eddy Simulation)
   c) Pyrolysis (Temperature dependent)
   d) Gas and transport (Passive tracer)
   e) Ember transport (We follow the particles)
   f) Heat transfer to the ground (Detailed radiation model, simple convection model with room for improvement, conduction not so important)

CURRENT STATE OF PHYSICS-BASED MODELS

1) Douglas Fir tree
   a) Modelled using WildFire Dynamics Simulation (WFDS)
   b) Tree is modelled as a cone of fuel particles (hence particle temperature)
   c) Qualitative agreement with experimental results



Mell, William, et al. "Numerical simulation and experiments of burning douglas fir trees." *Combustion and Flame* 156.10 (2009): 2023-2041.

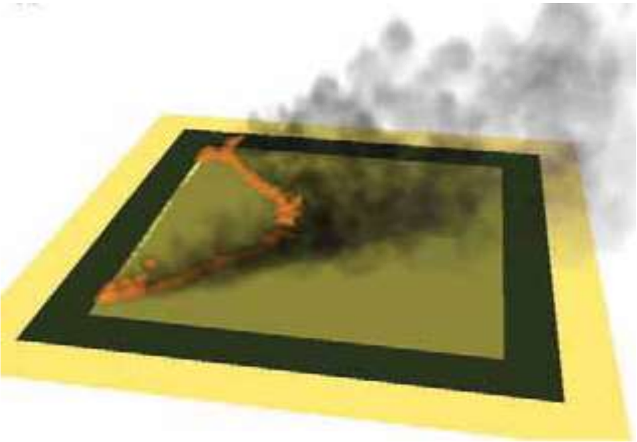
CURRENT STATE OF PHYSICS-BASED MODELS

2) Australian Grassland fire

a) Simulations using WFDS
b) Fire spread rate in agreement with experimental results
c) Fire front perimeter well modelled
d) Numerical method may not be robust: work in progress

(a)

(b)



(a) Photograph of experimental fire and (b) fire simulation of a 200mX200m grassland

Mell, William, et al. "A physics-based approach to modelling grassland fires."*International Journal of Wildland Fire* 16.1 (2007): 1-22.

CHALLENGES OF DEVELOPING MODELS

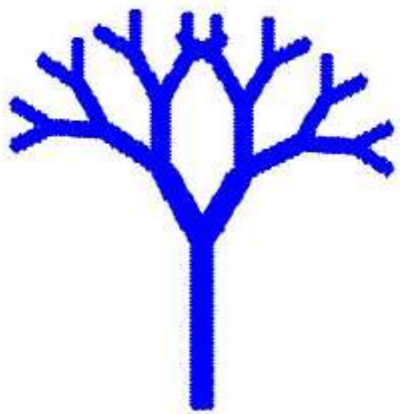
1) Bushfires depend on multiple length scales
   a) Overall fire front can be several hundred metres, to kilometres long
   b) The fire is effected by large weather systems which are many kilometres long
   c) Affected by fuel distribution which can vary over centimetres to metres
   d) Turbulent air flow through the tree canopy is affected by the size of the leaves
2) Numerical solution
   a) Cannot resolve all length scales
   b) Must model the effects of subgrid scale phenomena eg. turbulence models
   c) Must be fast, valid, and stable

OUR GOALS

1. Obtain accurate fuel data, and develop the model of pyrolysis
2. Develop models of Australian native trees
3. Flow through tree canopies
4. Firebrand production
5. Accounting for boundary roughness, such as terrain and houses

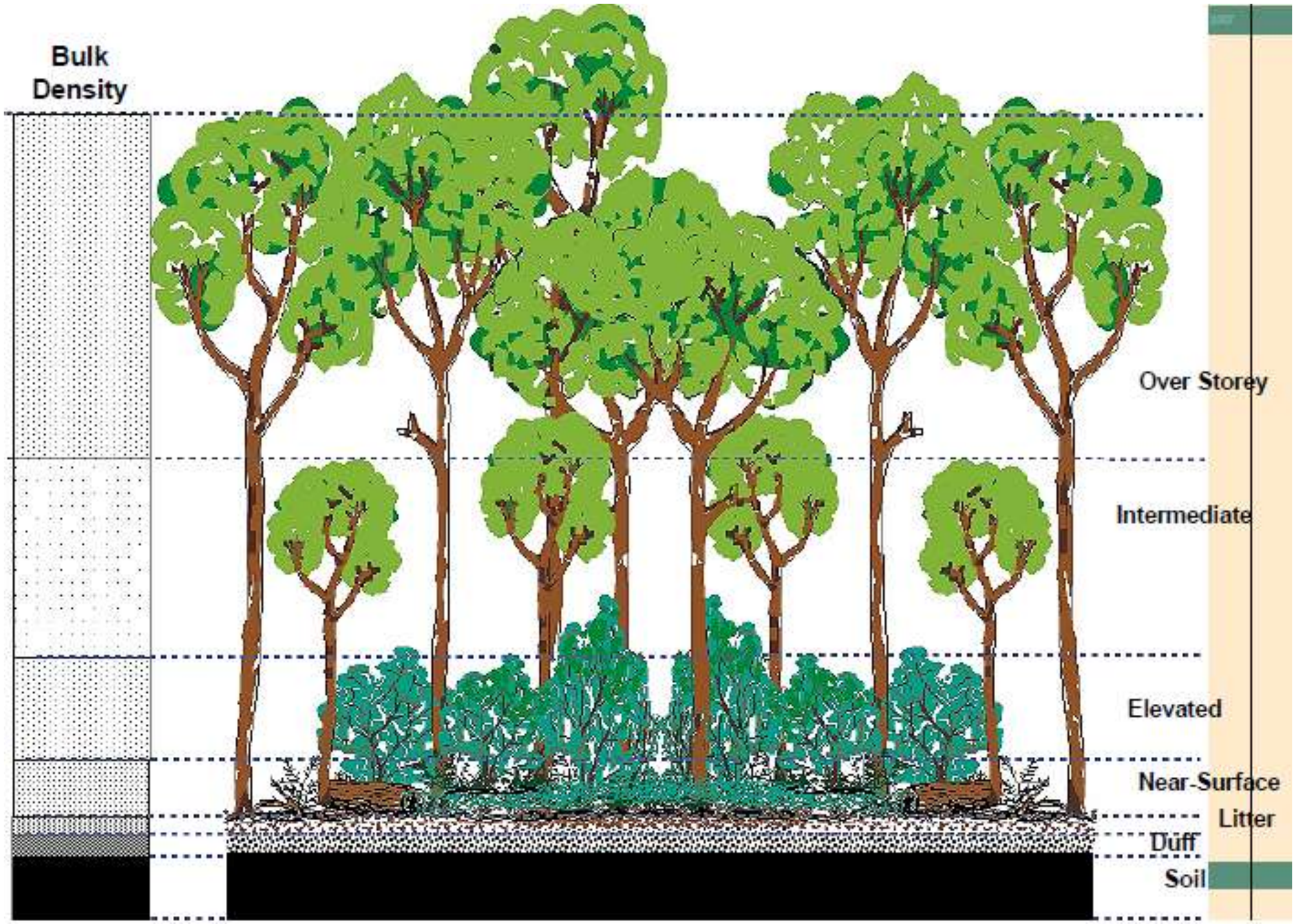
CURRENT DIRECTIONS: THEORETICAL

1) Fractal tree model
   a) Australian trees are typically a complicated shape
   b) correctly modelling the airflow through the canopy is important
   c) a fractal is a spatial pattern which repeats itself and decreases in size with every repetition
   d) Can use the self-similar nature of the tree to model the turbulent airflow through the canopy
   e) Want to compare this with existing models such as volume averaging



A fractal tree, note that each set of branches is similar to the previous set

MORE REALISTIC FUEL DISTRIBUTION



From Project Vesta, J. Gould et al.

CURRENT DIRECTIONS: THEORETICAL

2) Improving speed of computation

   a) Developing ways of modelling small scale details of the flow that make solutions more accurate and more efficient
   b) Two pronged attack: PhD project investigating improved subgrid-scale models for Large Eddy Simulation in real situations
   c) PhD project developing new methods of benchmarking subgrid-scale models and developing parallelised computer codes running on GPUs that enable practical codes to be very rapidly validated

OBTAINING ACCURATE DATA ON FUEL

Differential Scanning Calorimeter

Hot-disk Analyser

Thermo-gravimetric Analyser

Fourier Transformation Infrared Spectrometry

Cone Calorimeter

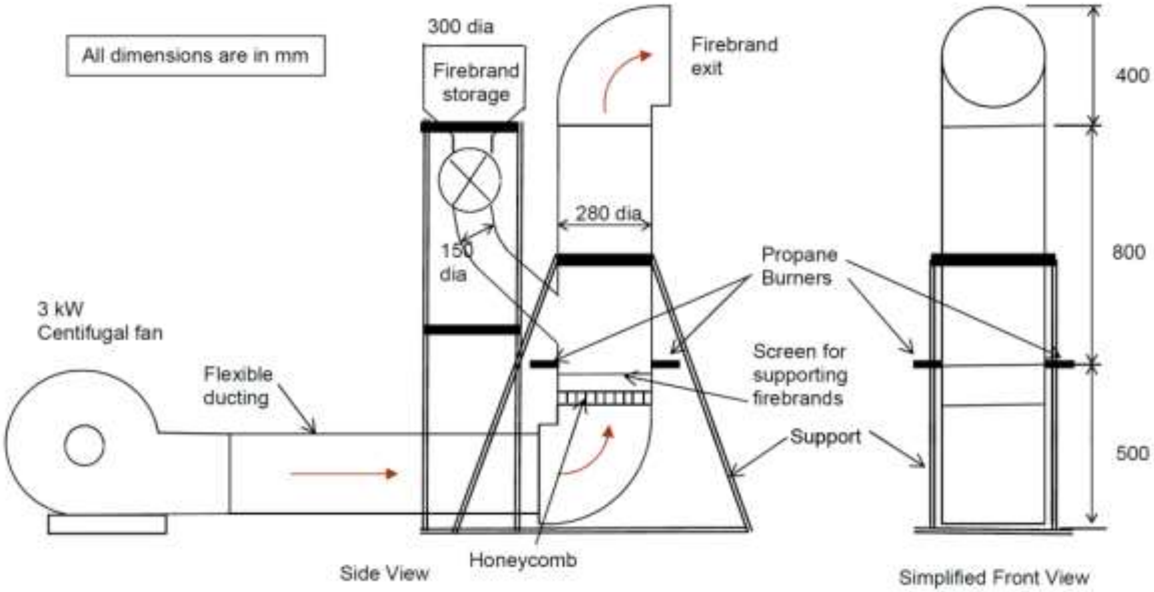
MODELLING THE BURNING OF AUSTRALIAN TREES

3 MW calorimeter

15 MW calorimeter

Firebrand generator

CURRENT DIRECTIONS: FIREBRAND GENERATION



A firebrand and ember generator has been designed, and a prototype constructed

Models of ember generation are being developed

IMMEDIATE USE OF OUR MODEL

1) Post-fire analysis
2) Provide insight into application tools for further improvement to non-physics based models
3) Calculate spread rate in changed climate and fuel conditions
4) Determining the size of firebreaks
5) Determining the sites of infrastructure

FUTURE DIRECTIONS

1) Transforming physics-based models from laboratory scale use to community scale use (modelling some field measurements of Project Vesta), eventually to landscape scale (in hybrid form)
2) Coupling with weather model
3) Incorporate LiDAR data.
4) Translating pure and fundamental research in the field of fire and computational science to the development of next generation fire prediction tool