ESF Exploratory Workshop
Improved Quantitative Fire Description With Multi-Species Inversions Of Observed Plumes
Farnham Castle, 14-16 September 2009

Physical description of Forest Fires

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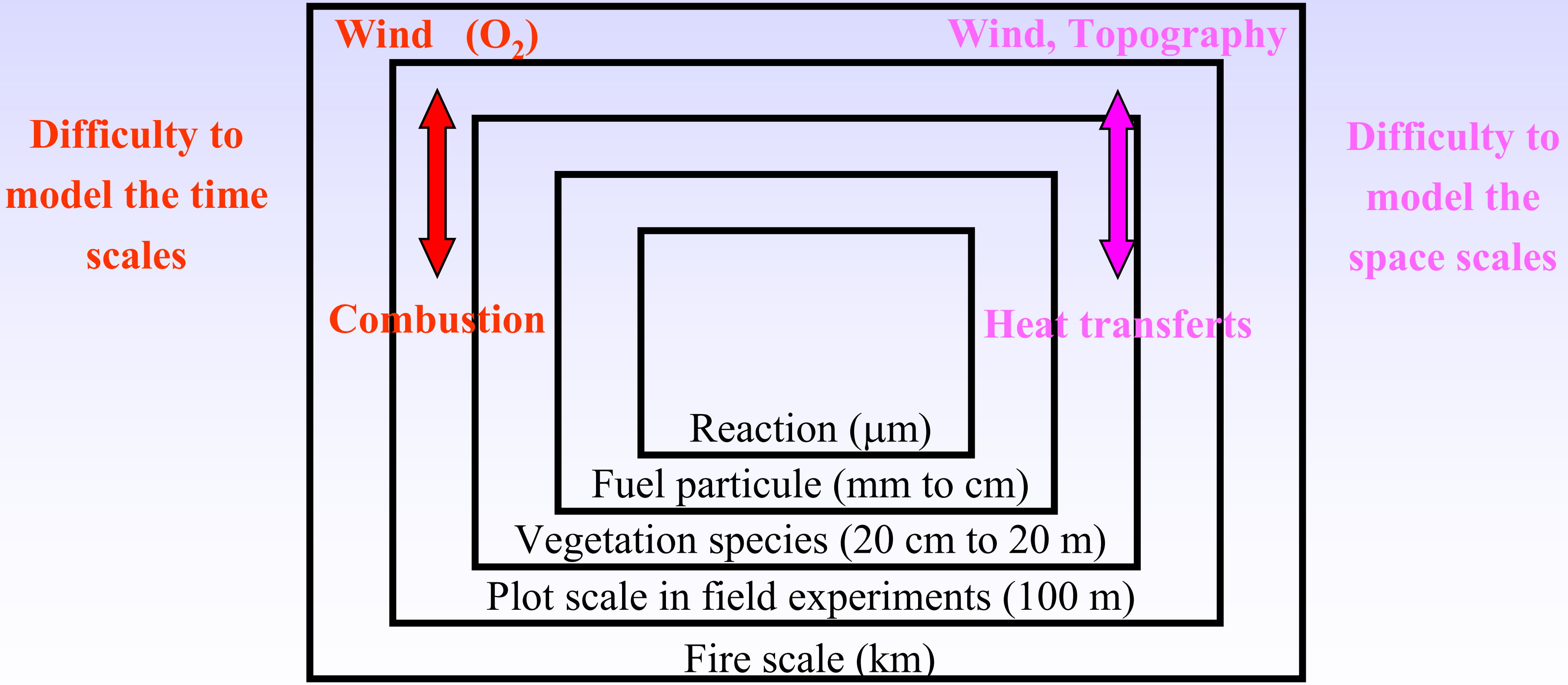
Introduction

- Physical description of forest fires aim to understand the behaviour of forest fires and predict their spreading
- This research started 50 years ago in Australia, USA and USRR
- The involved mechanisms are very complex
- The operational objectives are to predict the fire spread and to estimate the impact of the fire
  - The predictions are done thanks to fire spread models inserted in simulators
  - The impacts are estimated thanks to modelling and experiment

Fire Spread Modelling

Where does the difficulty in the modelling of forest fire lay?

- The Physical laws are known
- GIS and weather models provide the Environmental data



Difficulty in modelling the huge variable variability (fuel gases …)

Fire Spread Modelling

The problems in the modelling of forest fires are due to the numerical solving of mixed complex problems at different scales

Three kinds of modelling:

- Empirical (Mc Arthur, 1966; simulator = Fire grass meter)
- Semi-empirical (Rothermel, 1972; simulator = Farsite or Behave)
- Physical
  - Simplified (Albini, 1981; simulator in development by our team)
  - Detailed (Grishin, 1996; simulator = Firetec or Firestar)

Two ways to describe fire spreading with physical modelling:

- Detailed models that describe as finely as possible the mechanisms

Drawbacks: small times and lengths

Advantages: detailed description of the phenomena

Knolwedge and prevention

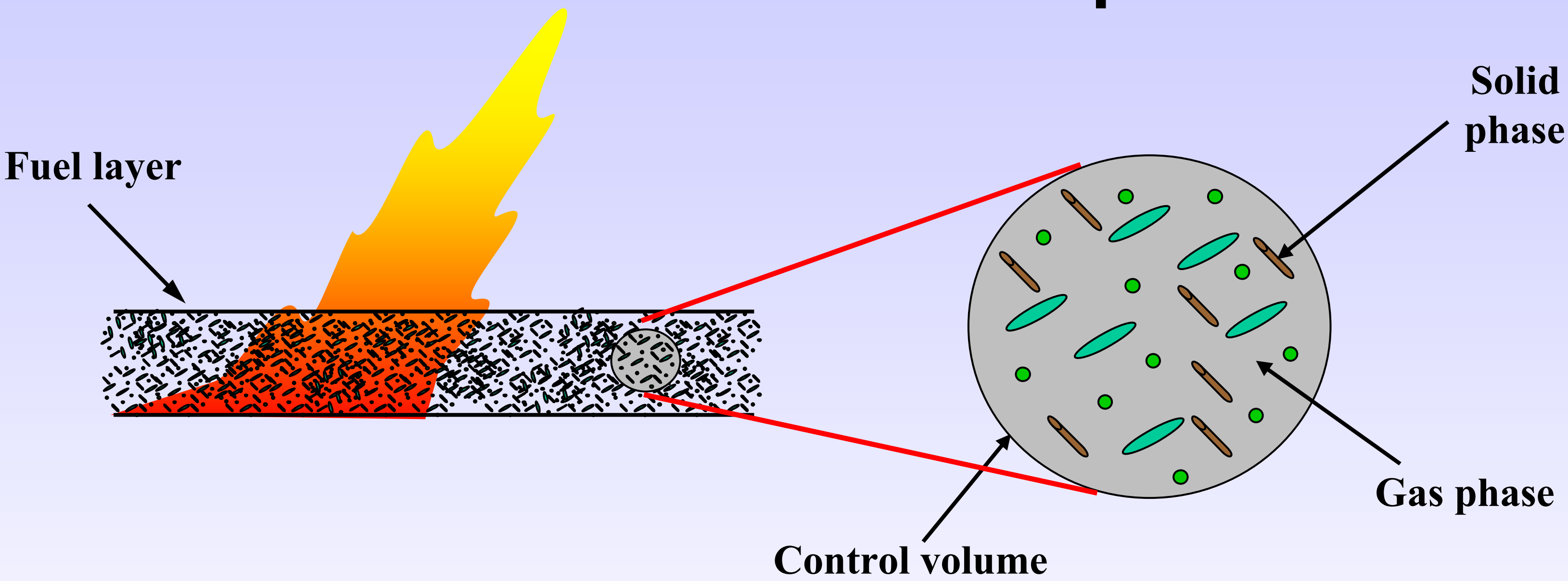
- Simple models that only take into account the main mechanisms involved in fire spreading

Drawbacks: less accurate and less general than detailed models

Advantages: possibility to implement them at the field scale

Simulation

Detailed models – A multiphase model



Gas Phase

- Convection
- Turbulence
- Gas mixture
- Combustion
- Radiation
- Soot

Transfers

Mass
Heat
Momentum
Energy

Solid Phase

- Heat transfer
- Drying
- Pyrolysis
- Combustion
- Radiation

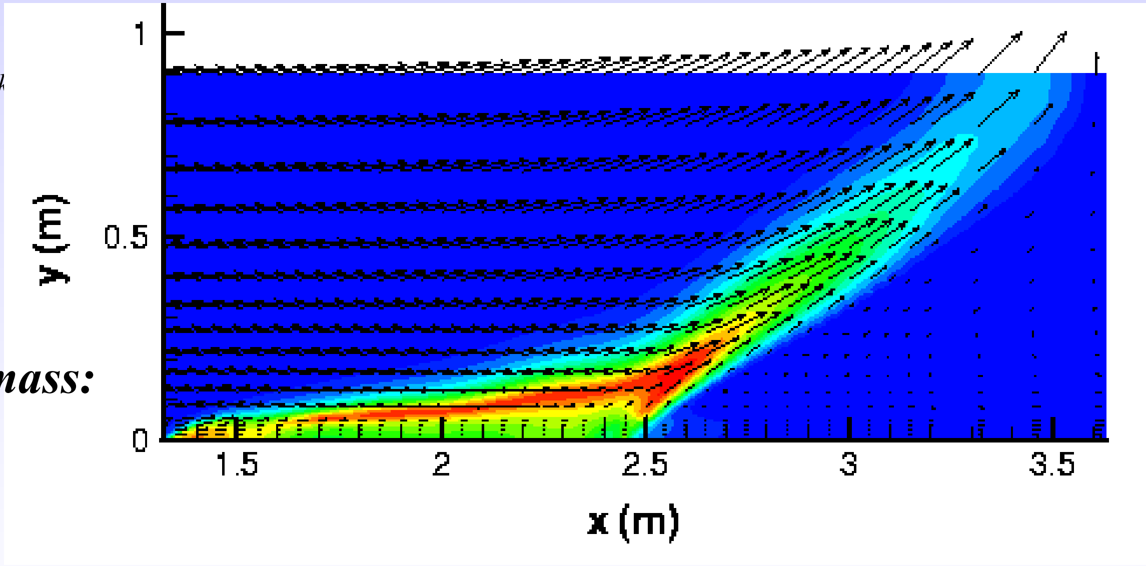
Detailed models – A multiphase model

- **For each phase: Mass, species, momentum and energy balances**

  Example – Mass balance:

$$\frac{\partial}{\partial t}\left(\alpha_g \left\langle \rho_g \right\rangle\right) + \vec{\nabla}.\left(\alpha_g \left\langle \rho_g \vec{V}_g \right\rangle\right) = \sum_k \left[\dot{M}\right]_{gk}$$

$$\frac{\partial}{\partial t}\left(\alpha_k \left\langle \rho_k \right\rangle\right) = -\left[\dot{M}\right]_k^{surf} - \left[\dot{M}\right]_k^{pr}$$



- **Interface relationships**

  Example – Interface equation for mass:

$$\left[\dot{M}\right]_{gk} = \left[\dot{M}\right]_k^{surf} + \left[\dot{M}\right]_k^{pr}$$

- **Sub-models**

  Example – Arrhenius type laws

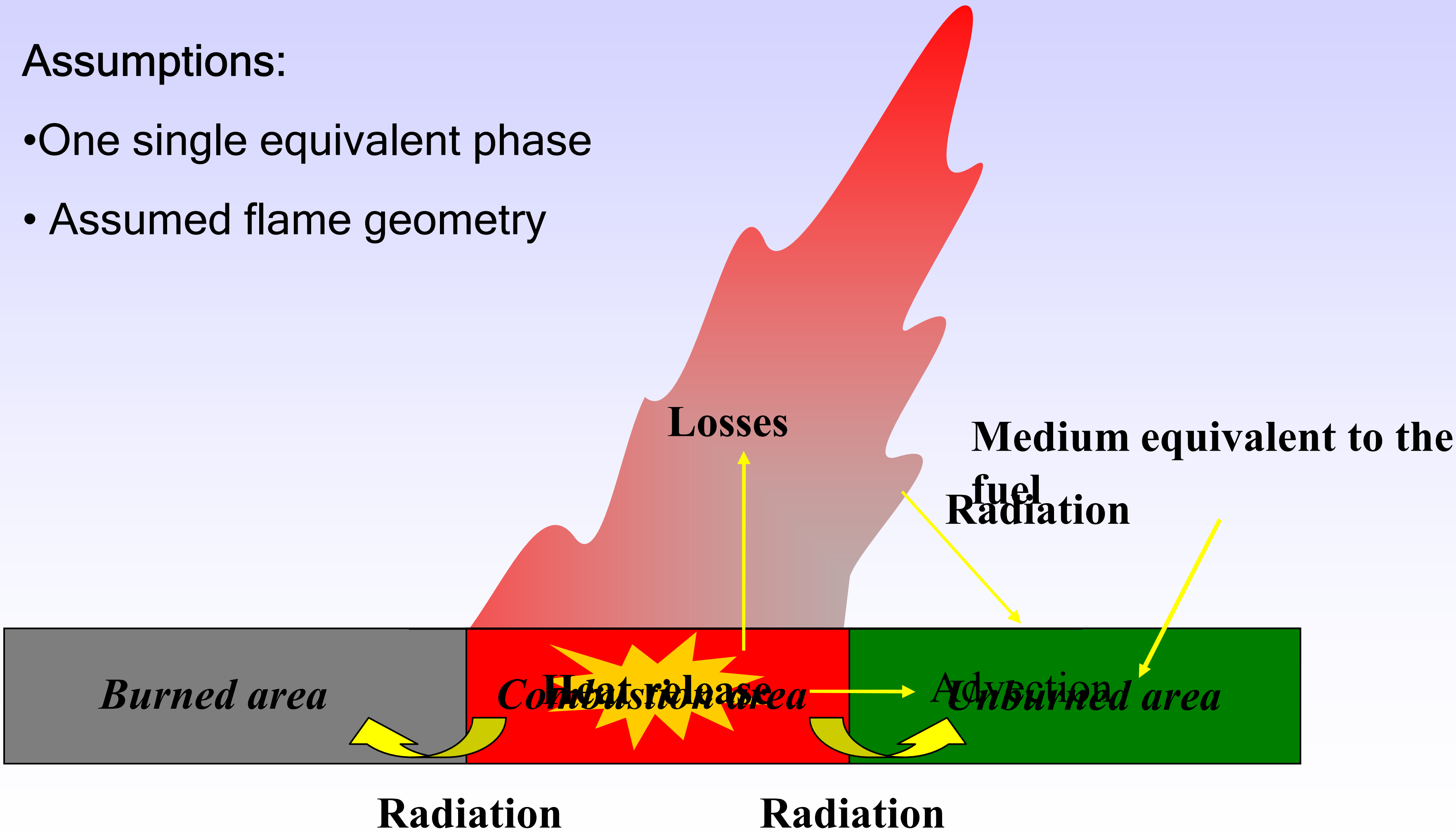
- **Radiative Transfer Equation**

$$\vec{e}.\vec{\nabla}\left(\alpha_g \left\langle L_g^{\Omega} \right\rangle\right) + \sum_k \sum_p \int_{S_{pk}} g\, L_g^{\Omega}\, \vec{n}_g.\vec{e}\, dS = -\alpha_g \left\langle a_g^{\Omega}\, L_g^{\Omega} \right\rangle + \alpha_g \left\langle a_g^{\Omega}\, L_0^{\Omega} \right\rangle$$

Simplified models – A semi-Physical model

Assumptions:

- One single equivalent phase
- Assumed flame geometry



Fire Spread Modelling

Energy balance

$$\frac{\partial T}{\partial t} + k_v \vec{V}_g . \vec{\nabla} T = -k(T - T_a) + K \Delta T - Q \frac{\partial \sigma_k}{\partial t} + R$$

Radiative transfer

$$\phi_{fl-dv} = a_v \varepsilon_{fl} B T_{fl}^4 \int_{S_{fl}} \frac{\cos\varphi_{fl} \cos\varphi_v}{\pi r^2} dS_{fl} dS_v$$

Mass conservation

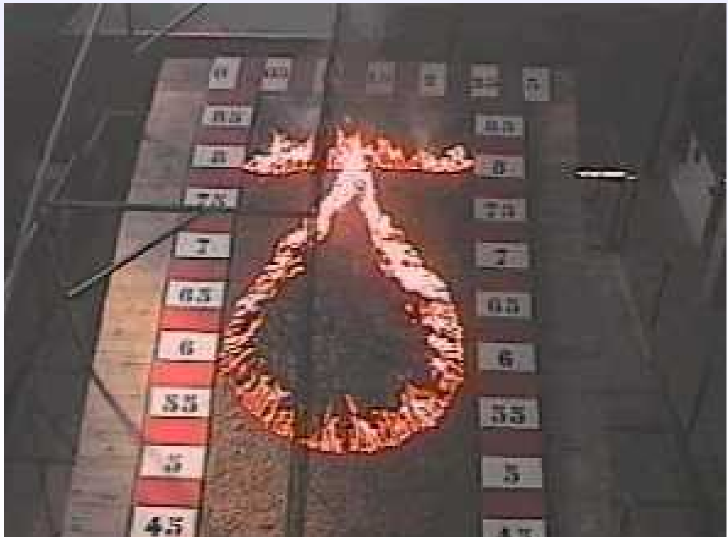
$$\frac{\partial V_{g,x}}{\partial x} + \frac{V_{g,x}}{\rho_g} \frac{\partial \rho_g}{\partial x} = -\frac{V_{g,z}(\delta)}{\delta} - \frac{1}{\rho_g \delta} \frac{\partial \sigma_k}{\partial t}$$

Buoyancy

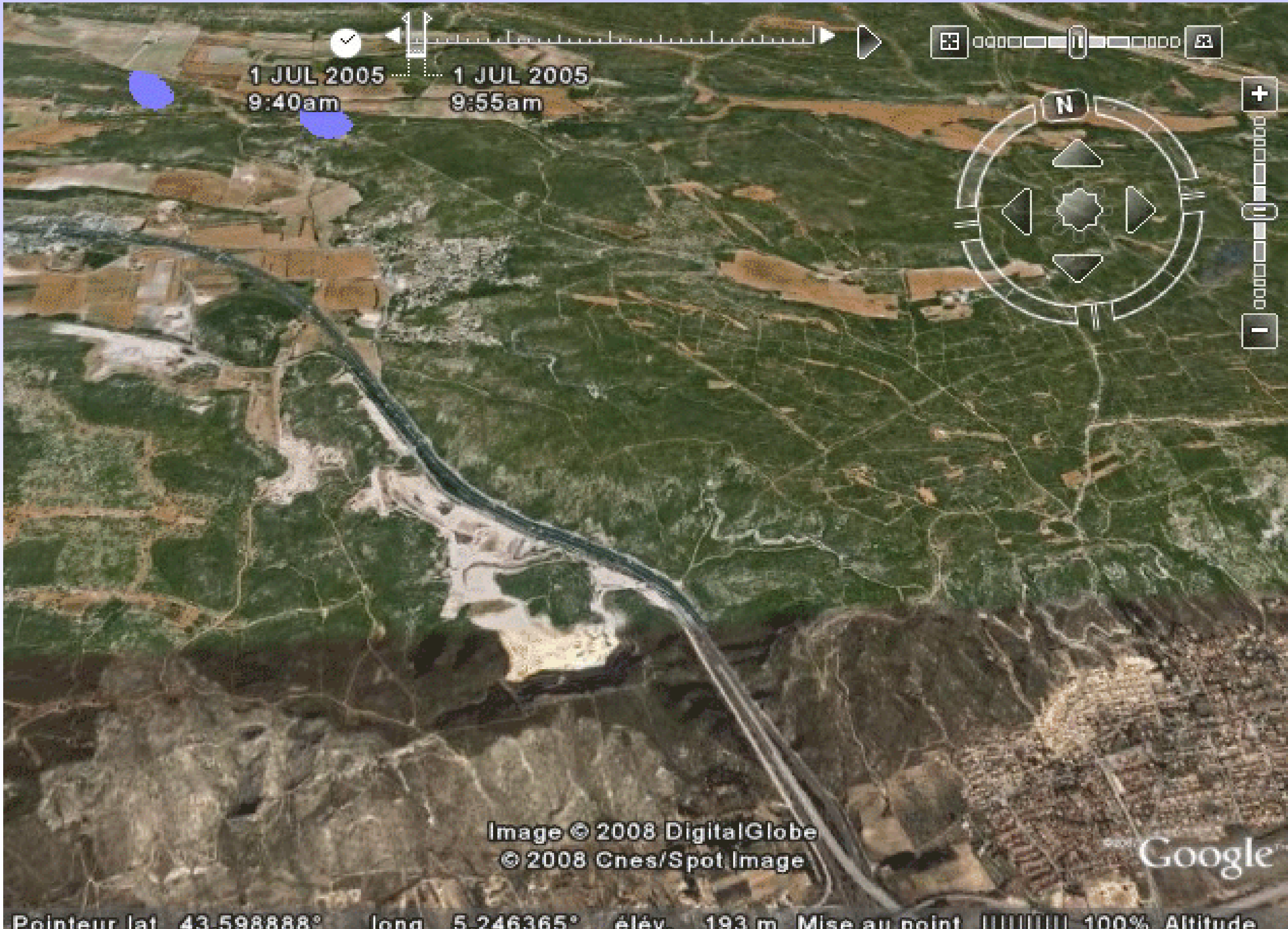
$$V_{g,z}(\delta) = \chi \sqrt{2\delta \left(\frac{T}{T_a} - 1\right) g \cos\phi_{sl}}$$

Perfect gas

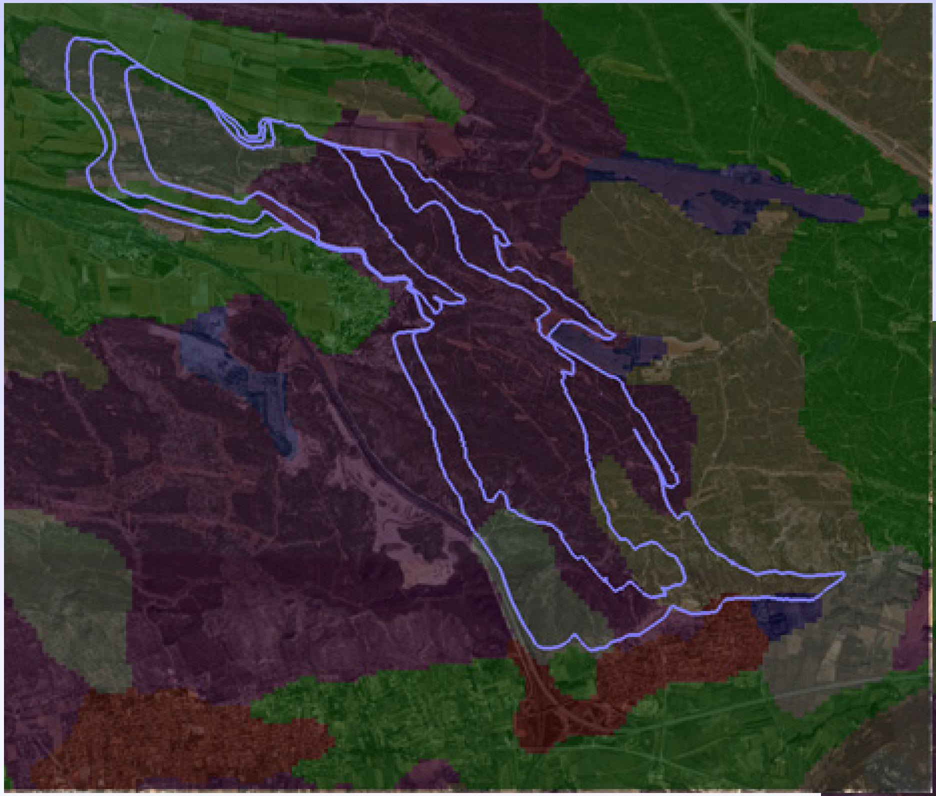
$$\rho_g T = \rho_a T_a$$

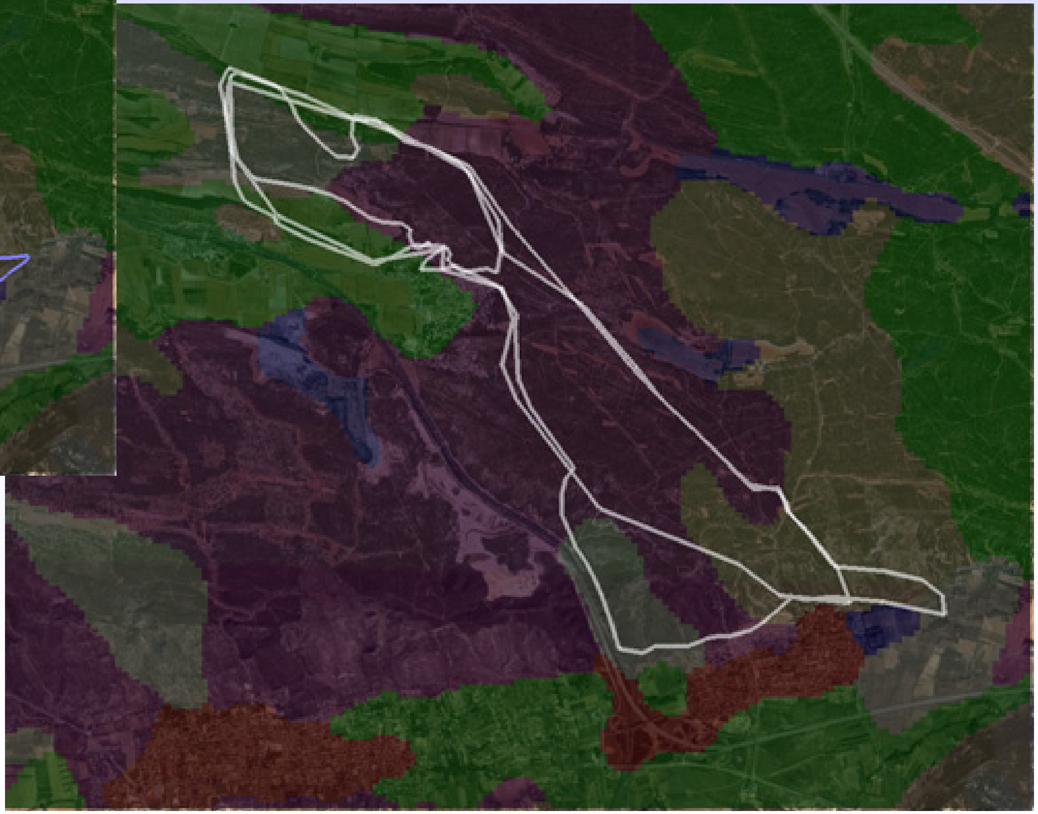


Fire Spread Modelling

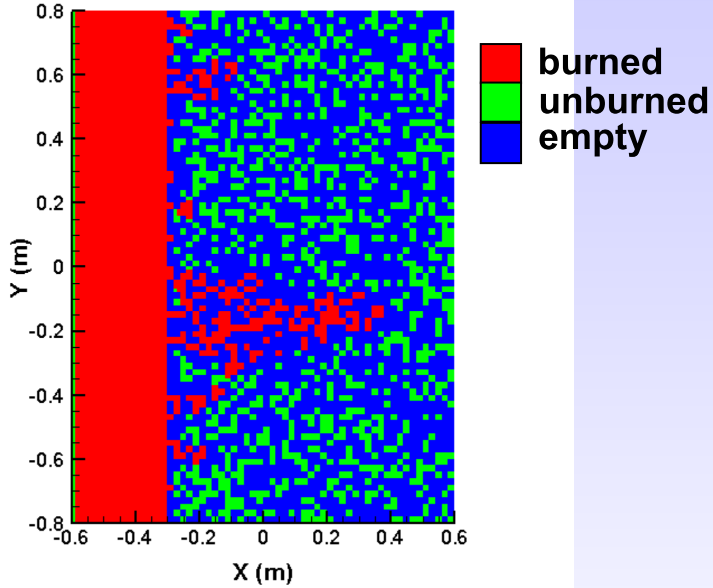


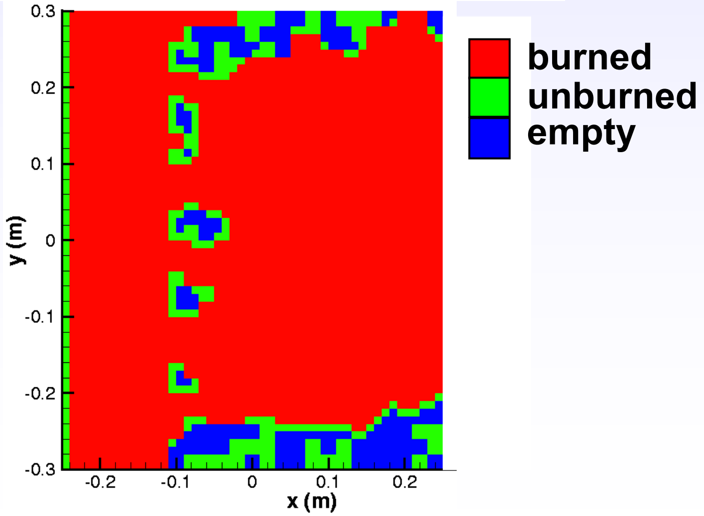
Fire Spread Modelling





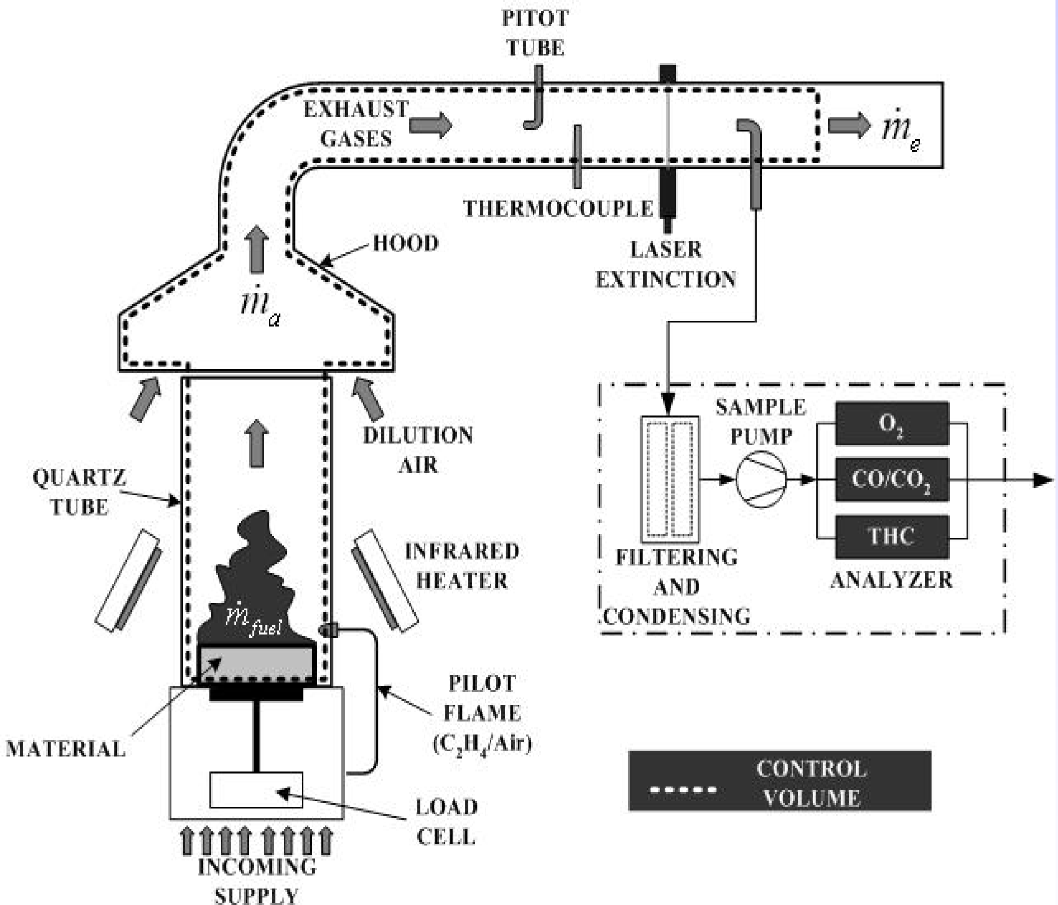
Modelling Heterogeneity – Non flammable areas



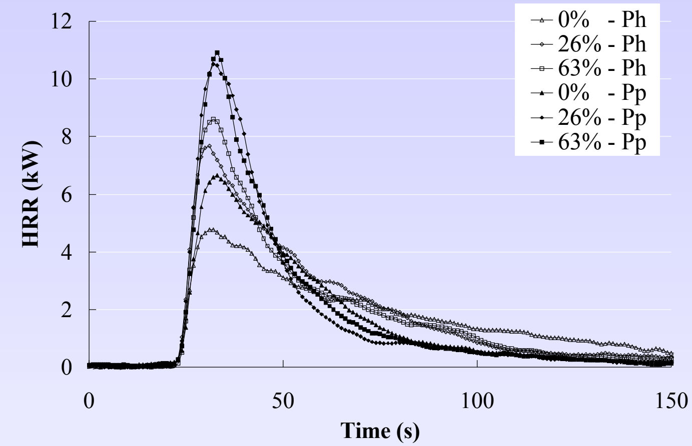


Fire Impact

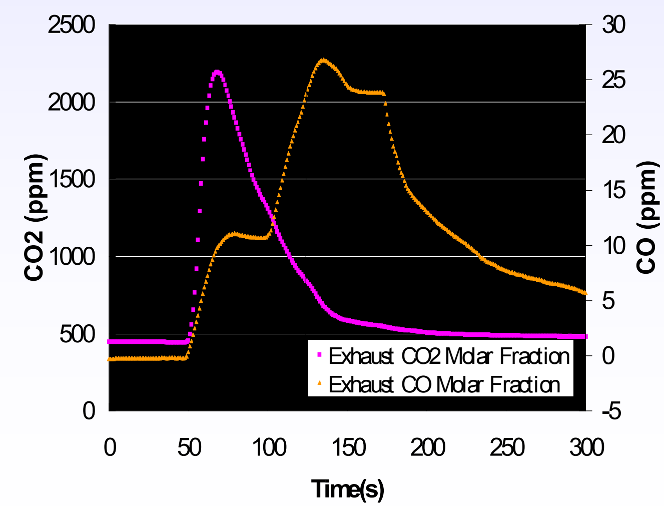
- Experiments under controlled conditions (heat flux, flow)



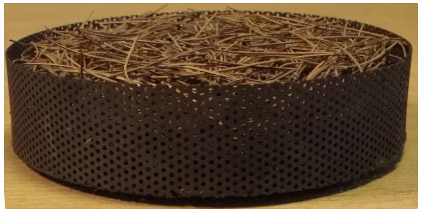
Fire intensity:



Fire emissions:



BRE Centre for Fire Safety Engineering



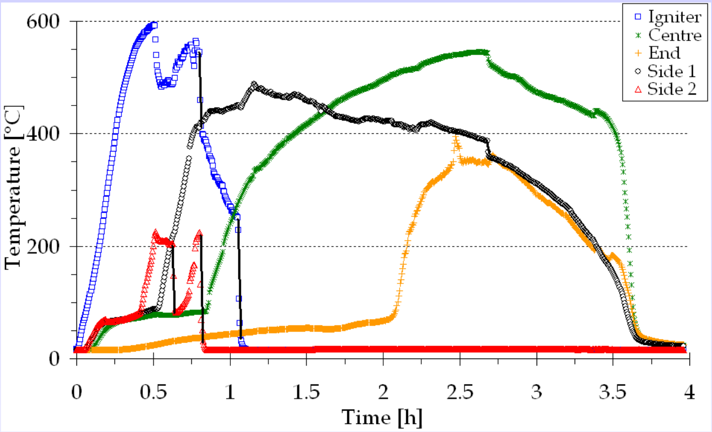
Fire Impact

- Smouldering

Fire Impact

- Smouldering

Fire Spread and Severity



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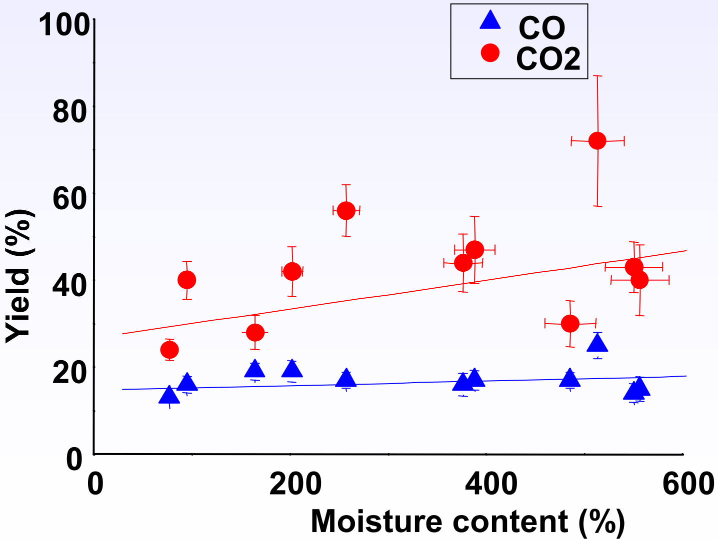
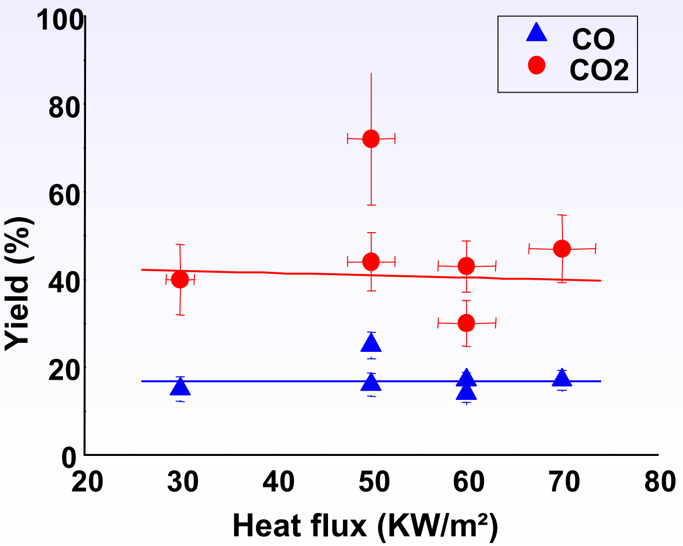
Emissions





Fire Impact

- Thermal impact (but also influence on vegetation and wind on fire spread)

Fire Impact

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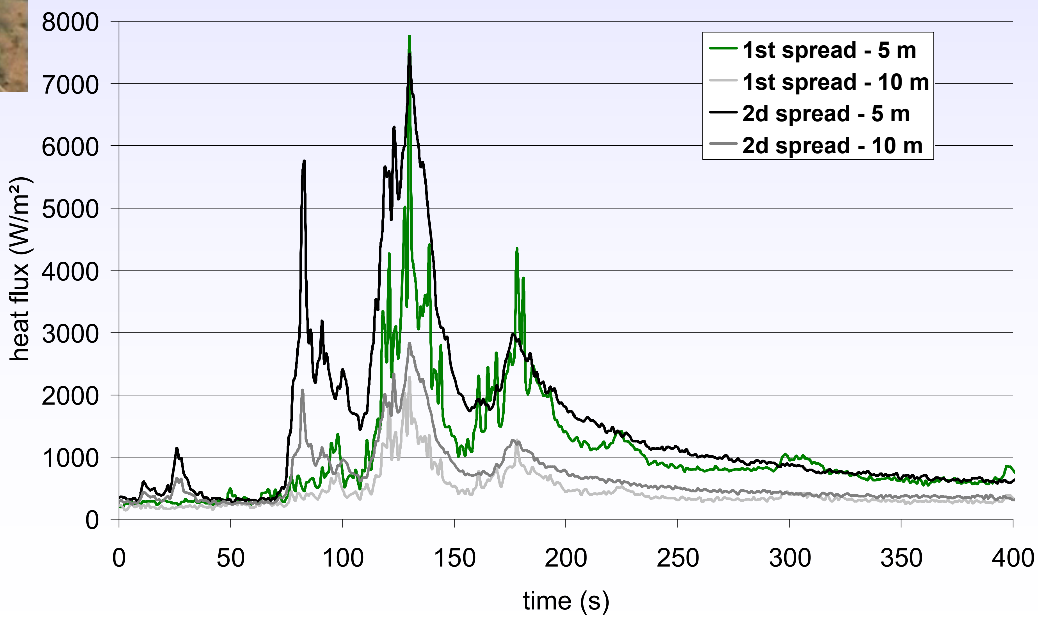
Limits of exposure

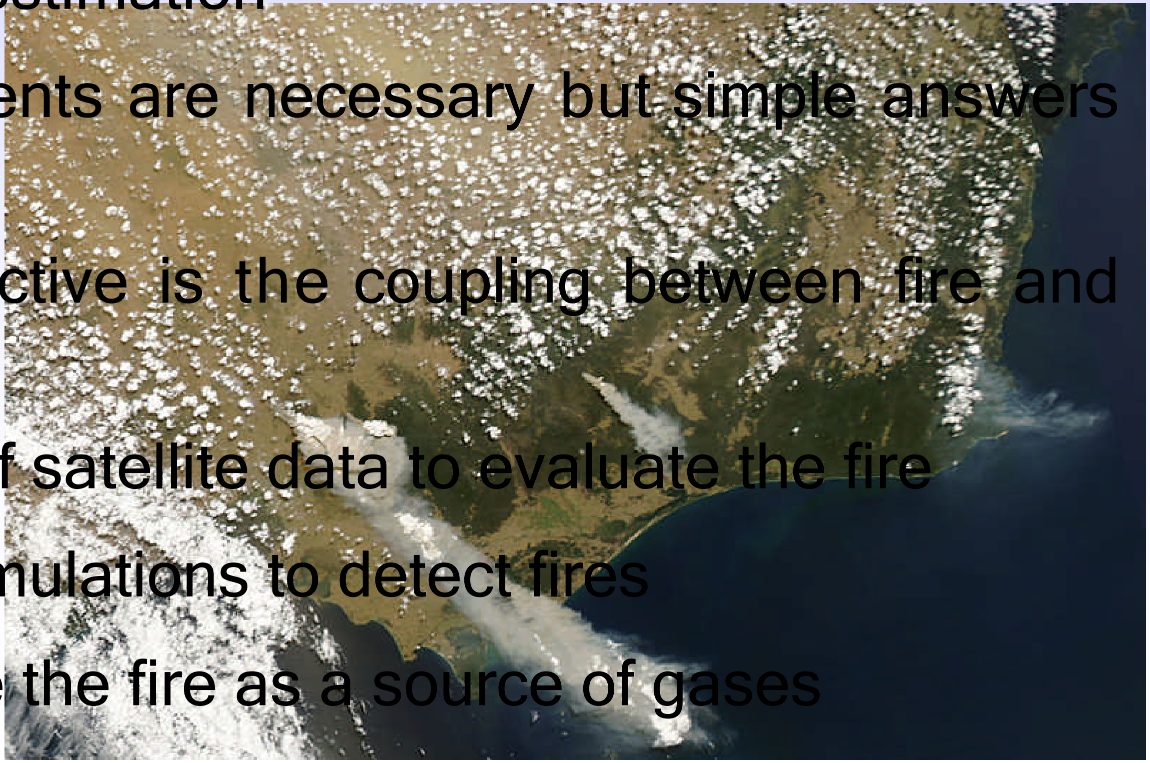
Firefighter: 7000 W/m² (90 s)

Unprotected person: 6400 W/m² (8 s)



Conclusions and perspectives

- Physical modelling of forest fires is a young science
- Two kind of tools arte developed:
  - Fire spread simulation
  - Fire impact estimation
- Many improvements are necessary but simple answers can be provided
- A strong perspective is the coupling between fire and atmosphere:
  - Integration of satellite data to evaluate the fire
  - Using fire simulations to detect fires
  - Characterize the fire as a source of gases



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