Wildland Fires

Where are we, how did we get here, and where are we going?

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THE UNIVERSITY *of* EDINBURGH

Where are we?

California (2007)

Scottish Highlands (2013)

Most expensive fires in US history (NFPA – adjusted loss in 2012 $)

4. Oakland Fire Storm (WUI) Oakland, California, October 20, 1991
   $2.5 billion

5. The Southern California Firestorm, San Diego County, California, October 20, 2007
   $2.0 billion

8. "Cerro Grande" (WUI), Los Alamos, New Mexico, May 4, 2000
   $1.3 billion

9. "Cedar" Wildland Fire, Julian, California, October 25, 2003
   $1.3 billion

11. "Old" Wildland Fire, San Bernardino, California, October 25, 2003
    $1.2 billion

Black Saturday Fires, AU$ 4.4 billion (including AU$ 647 million for loss of lives)

Greece Wildfires, 2007, $7 billion

Money spent on fuel treatment in the US over the last 10 years: $5.5 billion

Australia, Black Saturday and following days (Victoria State, February 7 – March 14, 2009):

- 173 fatalities
- 450,000 ha burned
- 3,500 buildings destroyed
- Confirmed sources: cigarette butts, lightning, power lines, arson, machinery

Worst bushfire-weather conditions ever recorded!
Temperatures > 40°C
Winds> 100 km/h

Where are we?

Fire eruptions *(Fire Service of North Corsica)*

Crown fires *(http://biologyprojectwiki.wikispaces.com)*

Massive fire plumes *(Wayne Hunnicut/Inciweb.org)*

Spot fires *(USDA)*

Where are we?

Peat fires around Moscow (August 6, 2010)

What do we have?

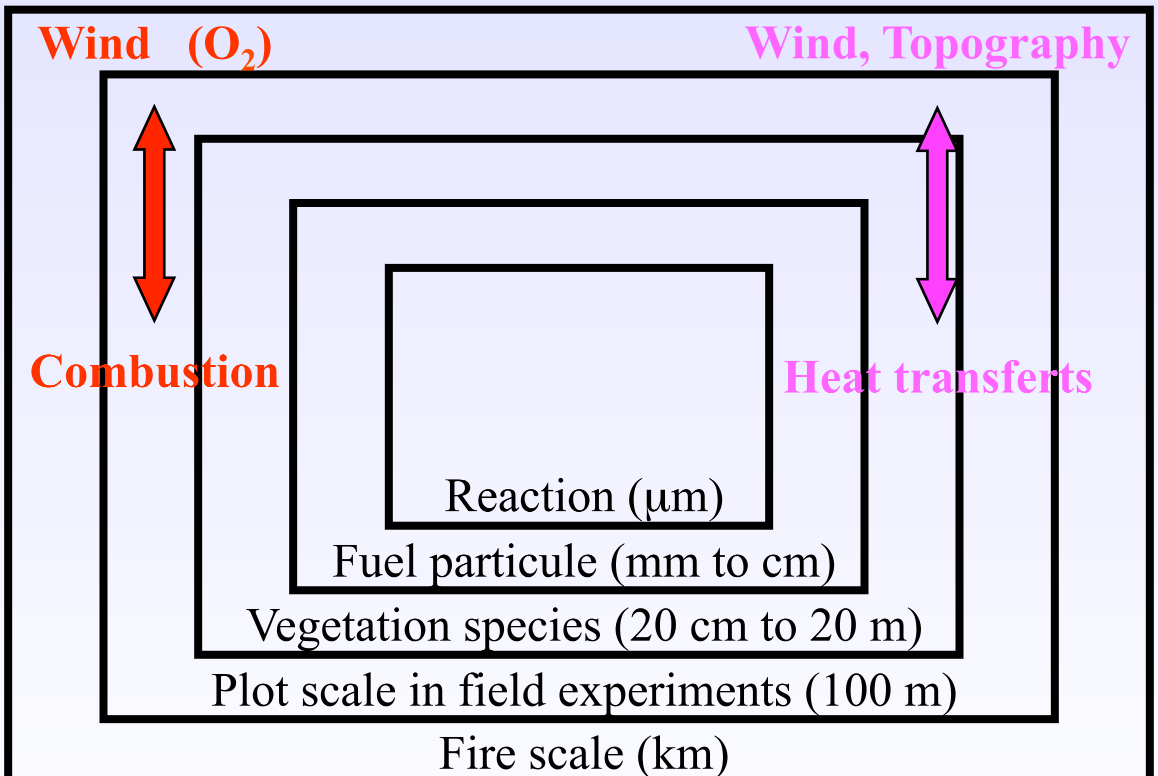
- Risk indexes
    - Canada / US / Europe
    - Not doing a very good job for some extreme climatic events
- Fire Spread
    - Semi-empirical models: landscape scale
    - CFD models: landscape scale (LANL) and WUI scale (WFDS)
    - Not doing a very good job at quantifying
- Fire Safety
    - Empirical knowledge / analytical approaches
    - Standards/codes (NFPA, ICC, ASTM)
    - Best-practice FireWise (USA), FireSmart (Canada), FireSafe (California)
    - Not very strong scientific bases

Why is it so difficult?

The scientific community knows the Physical laws

GIS and weather models provide the Environmental data

Difficulty to model the time scales



Difficulty to model the space scales

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

Where are we?

Knowledge transfer to end-users does not always require fully solved problems

- Coupling between fire and topography (trench effect)?
- Wind effect?
- Smoke or gas accumulation?


JRC Scientific and Technical Reports

Recent Forest Fire Related Accidents in Europe

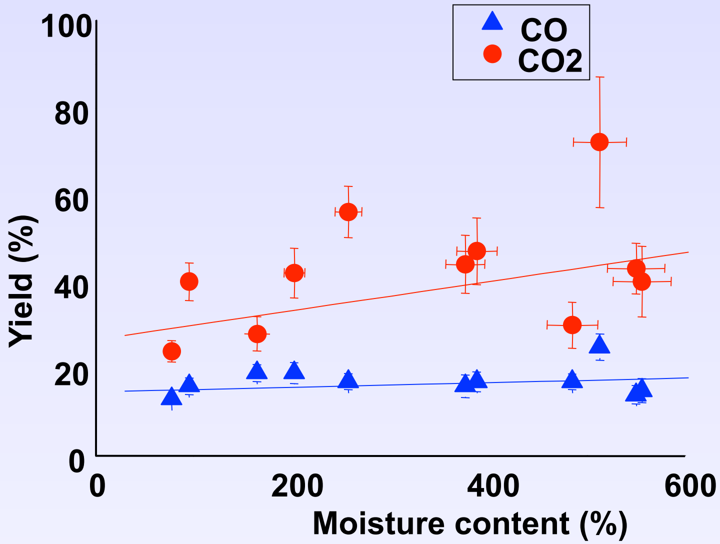
Domingos Xavier Viegas (Editor)

EUR 24121 EN - 2009

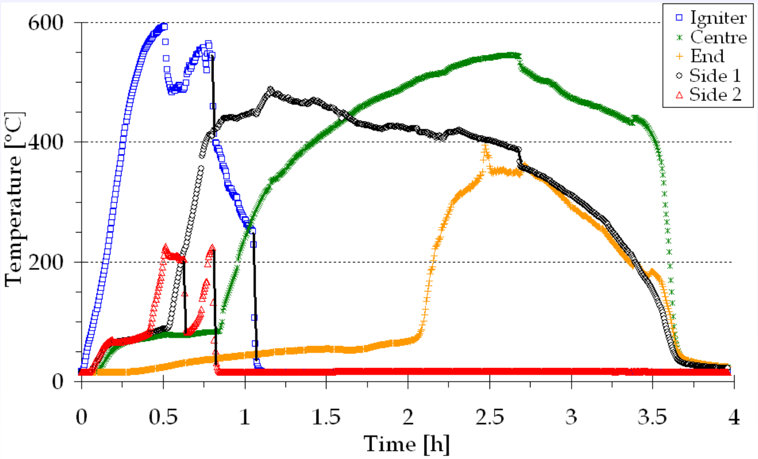
JRC EUROPEAN COMMISSION

Peat Fires

Emissions



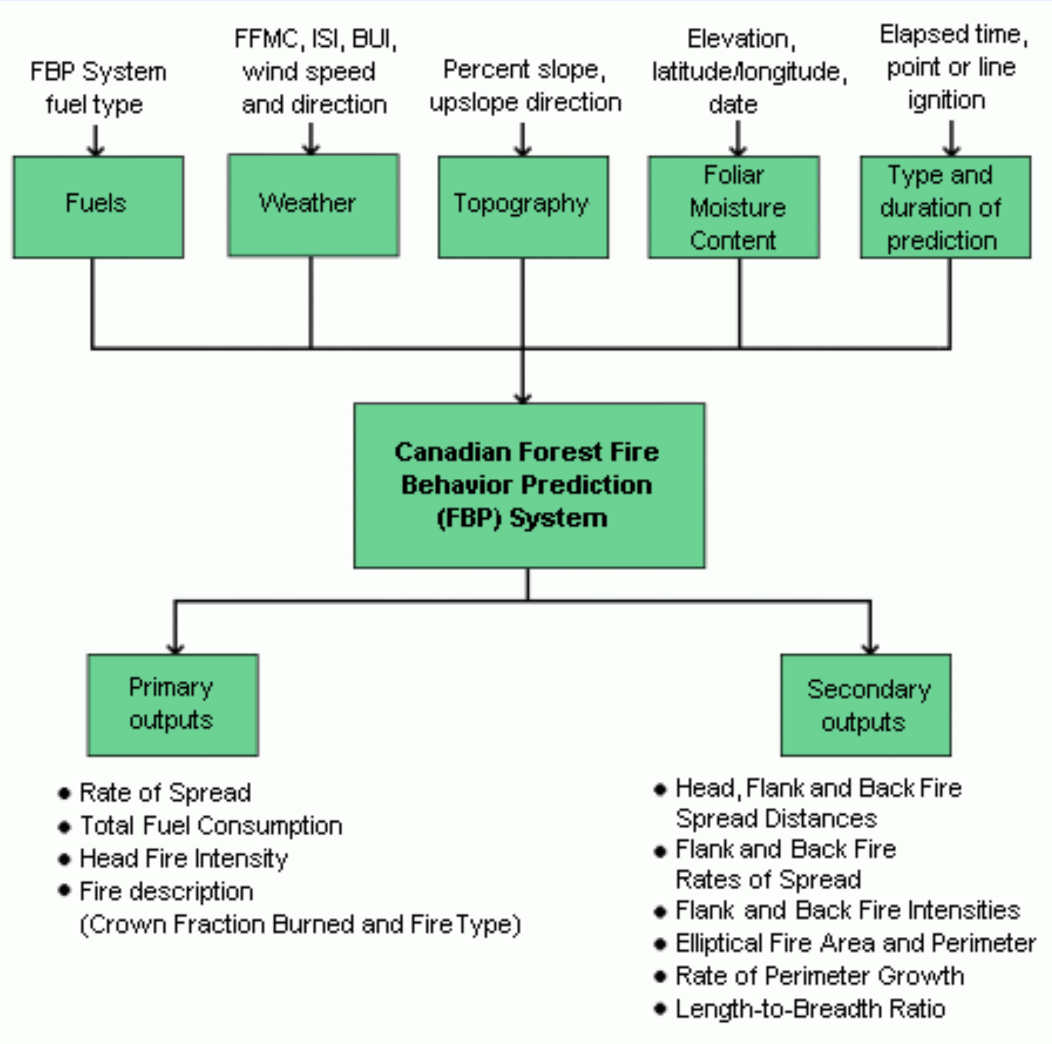
Fire Spread and Fire Severity

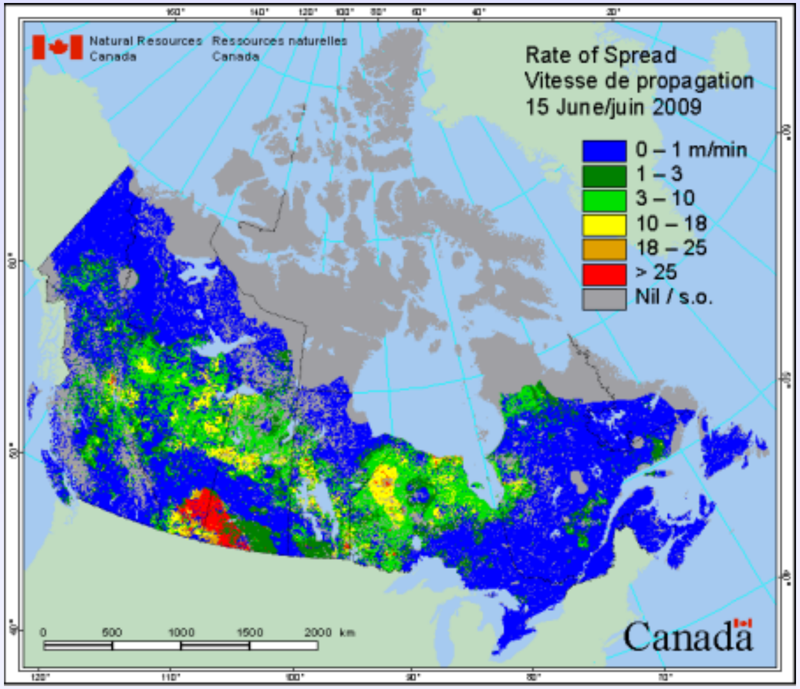


How did we get here?

- Experimental studies in the US (Show, 1919) later model development (Rothermel, 1972)
- Development of a research program in Canada (Wright, 1932)
- Fire Danger Meters in Australia (McArthur, 1966)
- Start of research programs in Europe (Thomas, 1971)
- Studies developed in USSR in parallel (Konev & Sukhinin, 1977)
- Forest services and public bodies drive the research in the US, Canada and Australia (university involvement is growing)
- Research mainly conducted in Universities in Europe and Russia

Empirical Modelling





$$RSI = a\,[1-e^{-b\,ISI}]^{c}$$

ISI: Initial Spread Index (function of Moisture content of vegetation and wind)

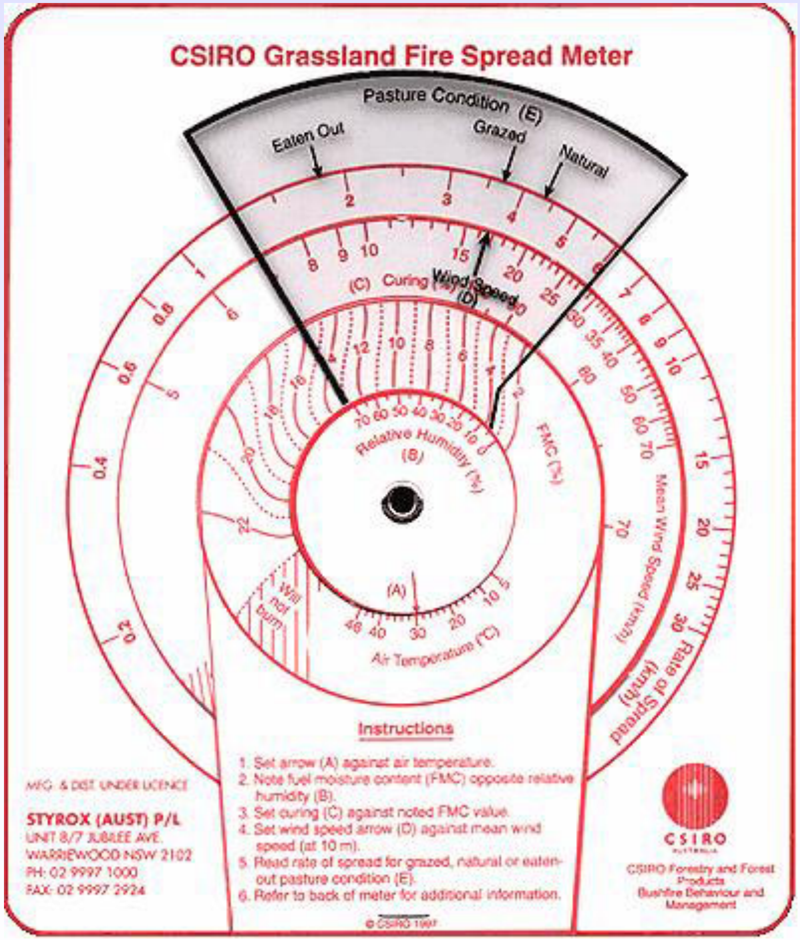
a,b and c are fuel dependent (8 classes for Canadian ecosystems)

Empirical Modelling

$$FFDI = 2e^{-0.45 + 0.987 \ln(10A) - 0.0345H + 0.0338T + 0.0234W}$$

FFDI = Forest Fire Danger Index
A: Fuel Availability Index (0<A<1)
H: Relative Air Humidity
T: Temperature (Celsius)
W: Wind speed

- FFDI calculated for different fuel moisture contents
- In use for 30 years (also Eucalyptus)
- Not applicable for other conditions



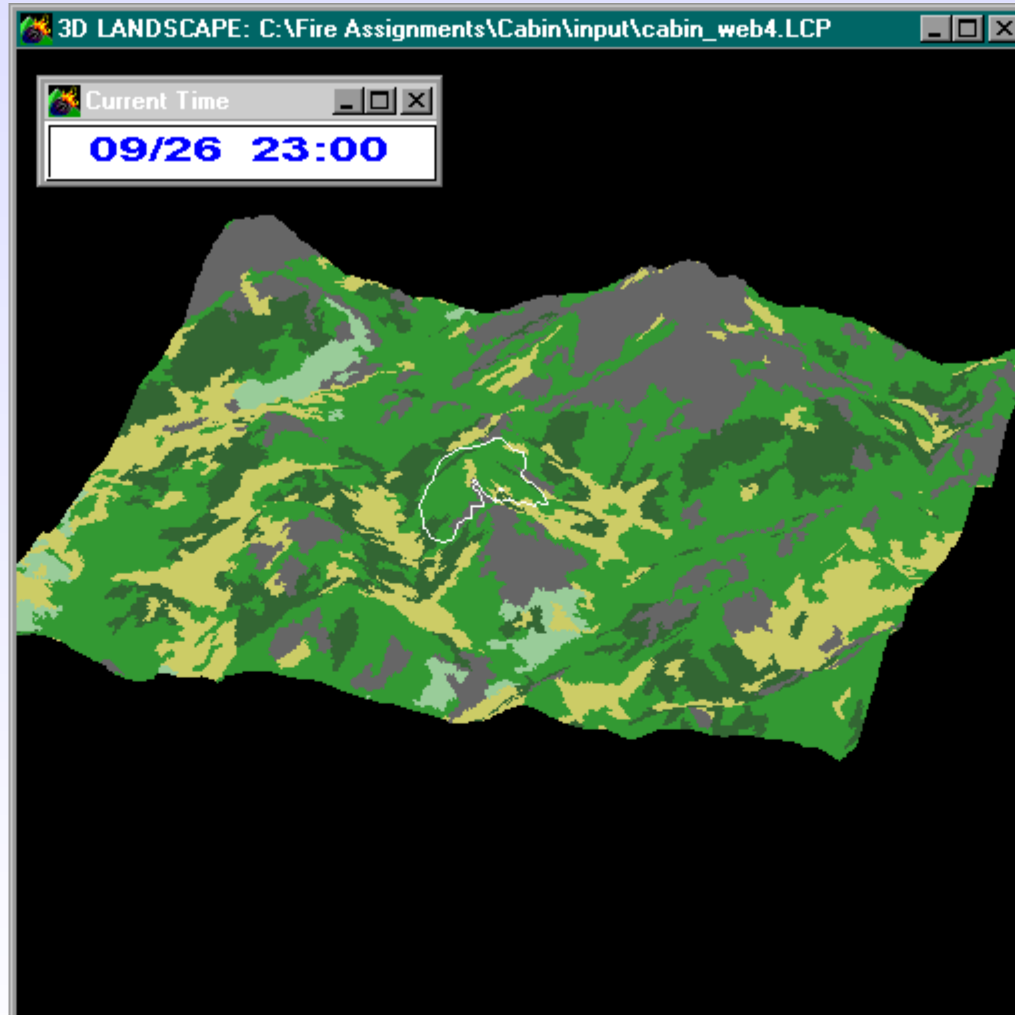
VI Short Course on Fire Behavior
15-16 May 2014
VI ICFFR, Coimbra

Semi-Empirical Modelling

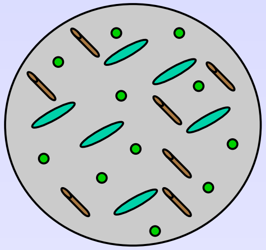
- One dimensional
- Steady-state
- Based on a single energy balance

$$R = \frac{I_{xig} + \int_{-\infty}^{0} \left(\frac{\partial I_z}{\partial z}\right)_{z_c} dx}{\rho_{be} Q_{ig}}$$

- Energy transmitted to the unburned fuel is proportional to the energy released by combustion
- No differentiation for heat transfers and heat production



Physical Modelling (detailed)



➢ For each phase

- Mass balance
- Chemical species balance
- Momentum balance
- Energy balance

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-modes

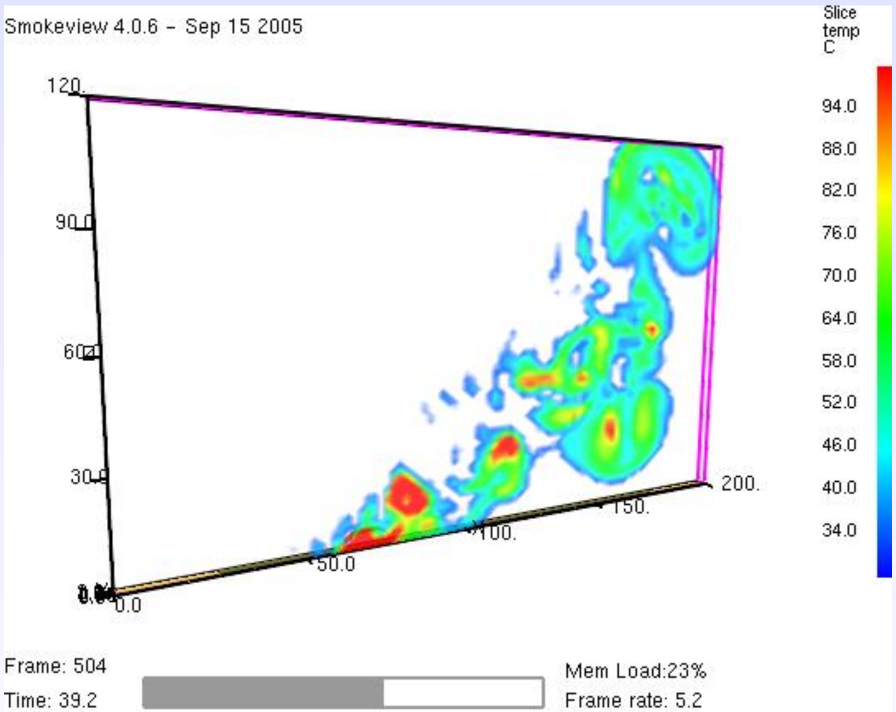
Example – Arrhenius type laws

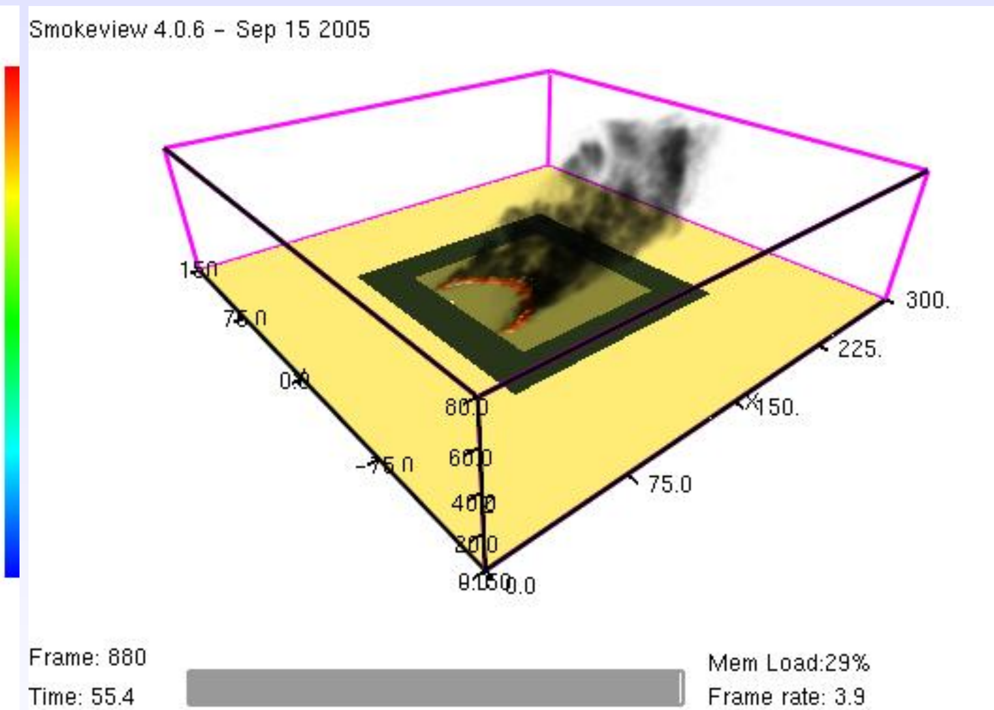
➢ R.T.E.

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

Physical Modelling (detailed)

WFDS (NIST / USFS)



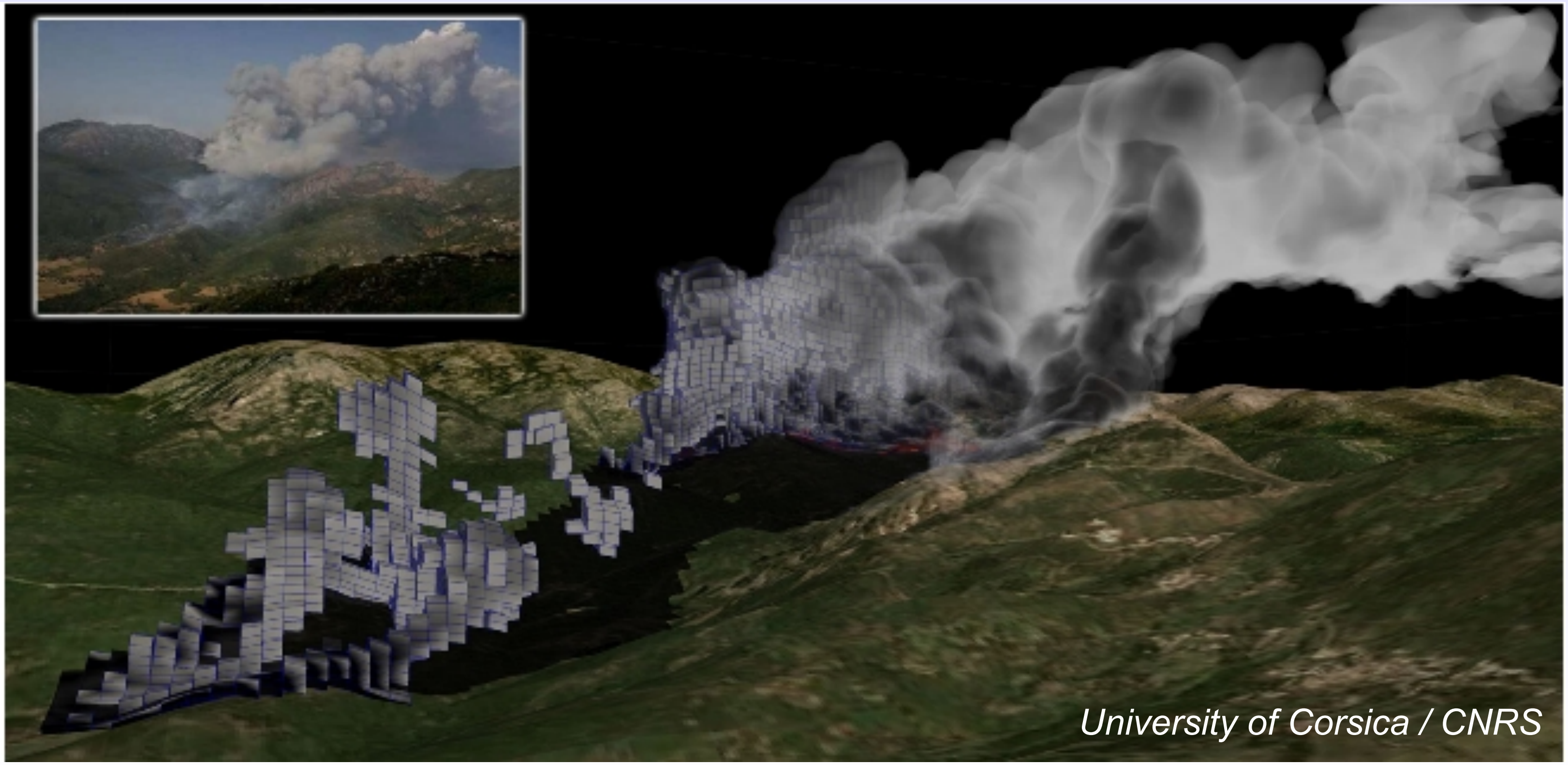


- Module in FDS
- Vegetation models
- Scale of the WUI

Physical Modelling (simplified)

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

Fire/Atmosphere Interactions



Experiments

Combustion → *Thermal transfer* → *Turbulence*

Maximal control ← *No control*

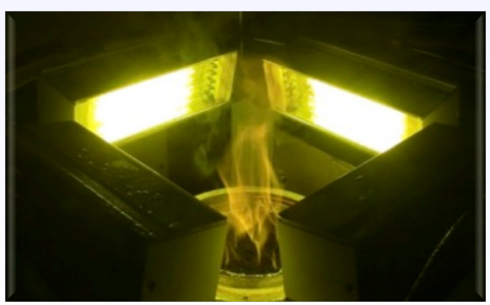
Microscopic (TGA, DSC)

Bench laboratory scale (small scale static fires or spreads)

Large laboratory scale (large scale static fires or spreads)

Field scale (from small shrub to tree canopy)

Uncontrolled fires (observation)

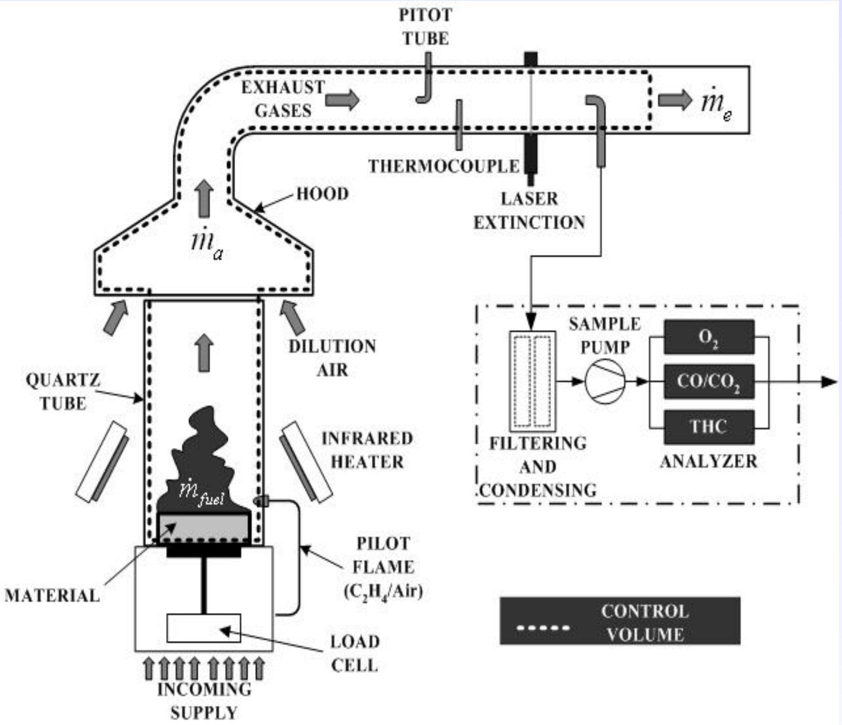


Where are we going?

Some very strong needs if we want to achieve quantification

- Better understand the fire fundamentals
  - Combustion
  - Coupling fire / vegetation (solid / gas interaction, layers interaction…)
- Better understand the fire dynamics
  - General fire behavior
  - Interaction of the fire with the ambient (wind, atmosphere, vegetation heterogeneities)
  - Extreme phenomena
- Changing environment
  - California fires
  - Forest in Far East of Russia
  - Fires in Scandinavia
  - WUI
- **Link with other research fields**
  - Fire science!
  - Future and past fire regimes
  - Emissions (CO_2 and pollution)
  - Forest dynamics / Ecosystems
  - Socio-economic changes / Management

Better understand the fundamentals



Applied conditions:

- No flow (natural convection)
- Different levels of forced flow

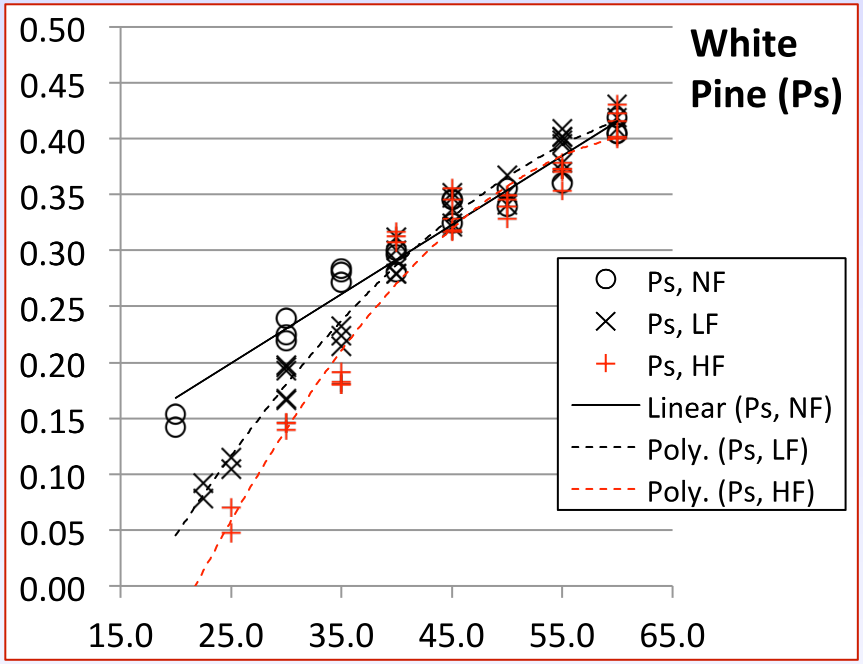
New design of fuel sample holders (porous beds)

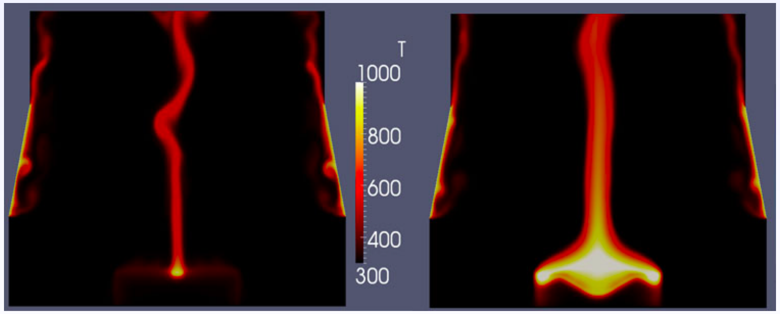
Pinus halepensis
0% basket

Pinus pinaster
63% basket

Where are we going?

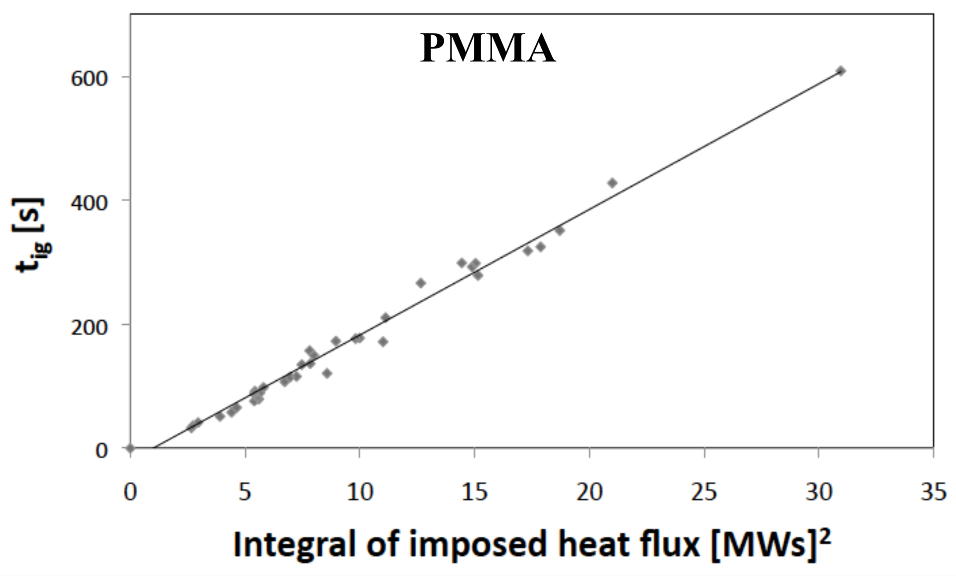
Ignition Behaviour





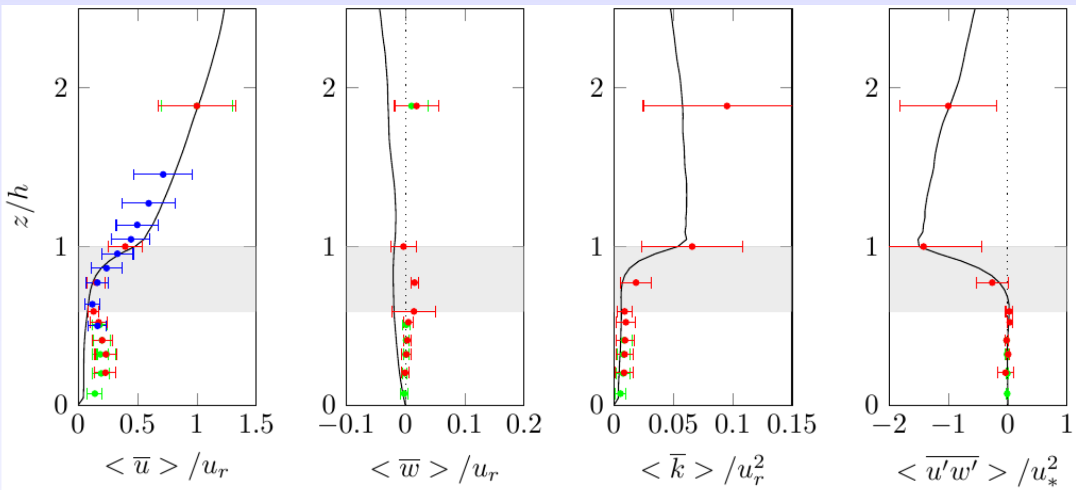
Simulations with FireFOAM

Decouple Fire / Structure

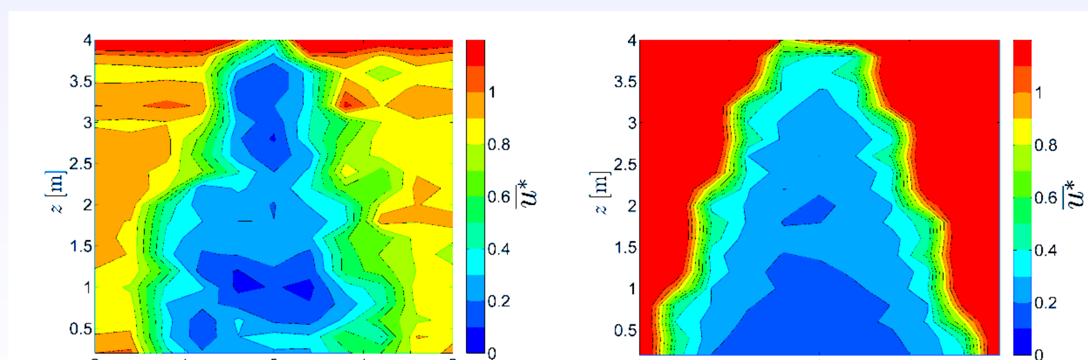


Develop the models and build trust

- Drag forces – Canopy

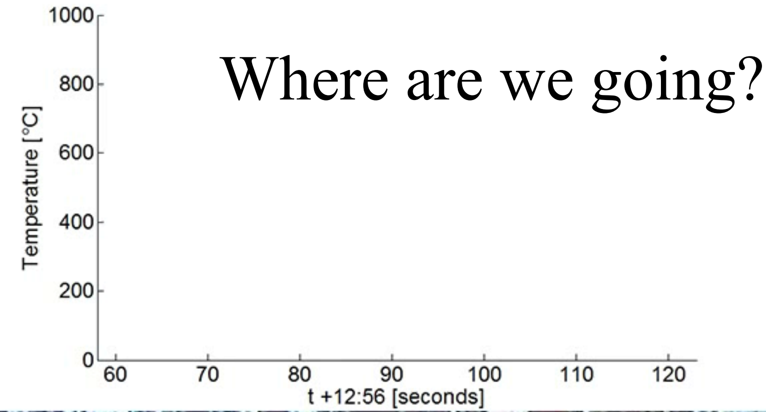


- Drag forces – Single tree:



U = 9 m·s^{-1}

Where are we going?



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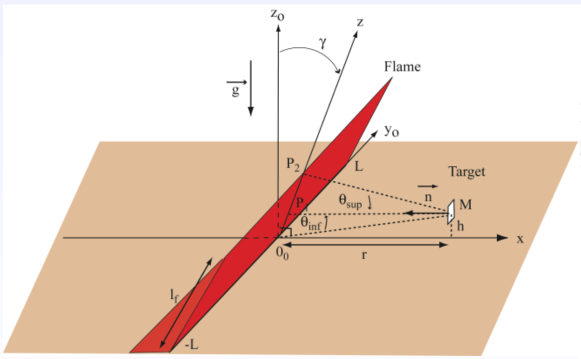
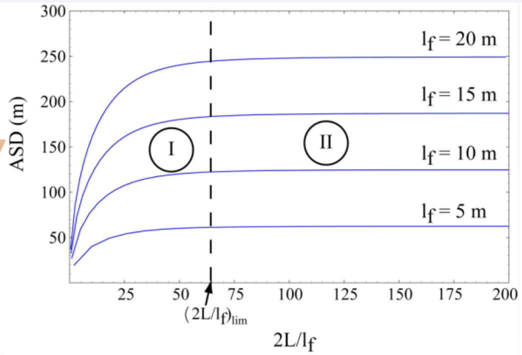
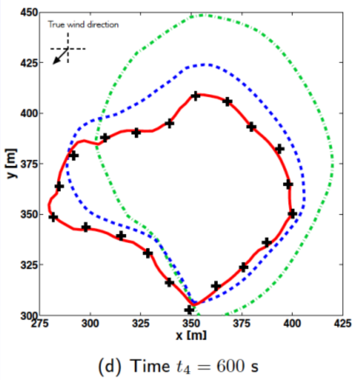
Where are we going?

- We need laboratory studies (including simulations) to understand the fundamentals and to develop and close the models
- We need reality checks in the field to feed more laboratory studies and to know the orders of magnitudes of the driving parameters
- We need validation studies to trust the models
- A big step would be to develop families of simplified physical models
- We always have to keep in mind that as engineers we must deliver





Safety distances



Data assimilation
(PhD Thesis of Melanie Rochoux)

Firebrand Generator
(NIST)