Forest Fire Model Validation

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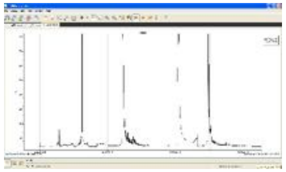
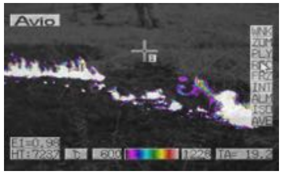
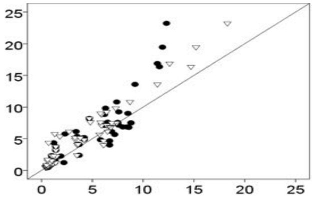




Objectives of fire field experiments

1. Collect fire behaviour data to calibrate and validate fire behavior models



2. Test equipments used during fire fighting (e.g., protection dispositives, fire shelter)

3. Assess building flammability at the Wildland Urban Interface

4. Correlate fire behavior to ecological fire effects (e.g. emissions, tree mortality)

5. Others objectives (e.g. fire operators risks, train firefighters…)

Summary

1. Why fire evolution modelling

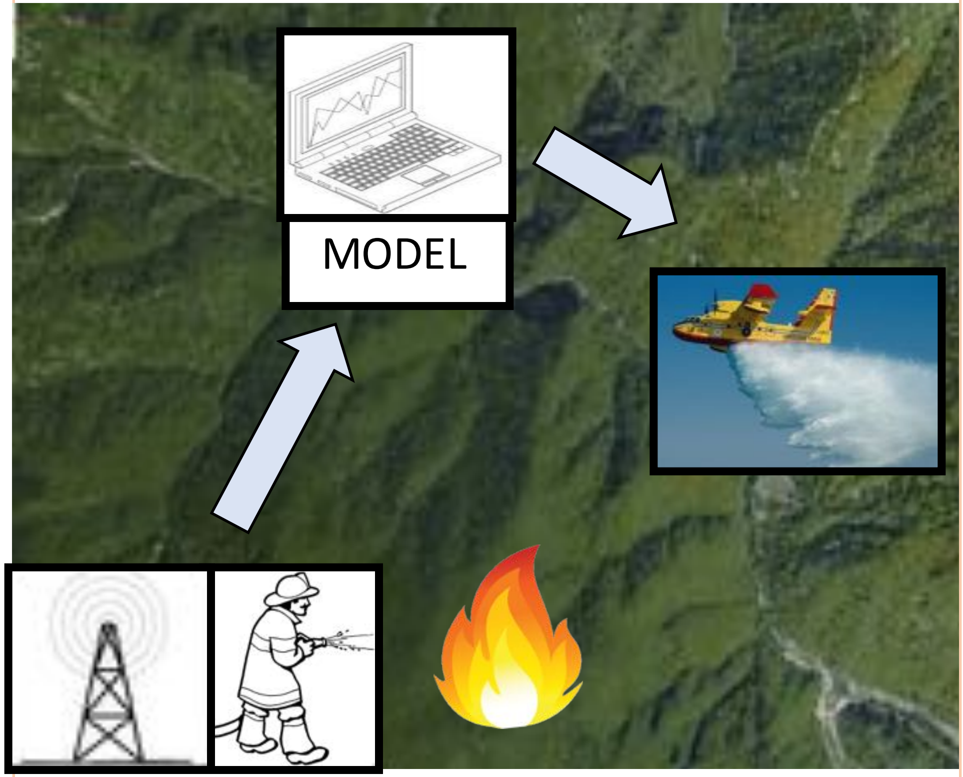
2. Experimental data

3. Empirical model validation through experimental data

4. Physical model validation through experimental data

Possible uses of models in operation

FAST SIMULATION MODEL DURING FIRE EVENTS



DETERMINISTIC APPROACH

MULTI-SCENARIO STOCASTIC MODEL

PROBABILISTIC APPROACH

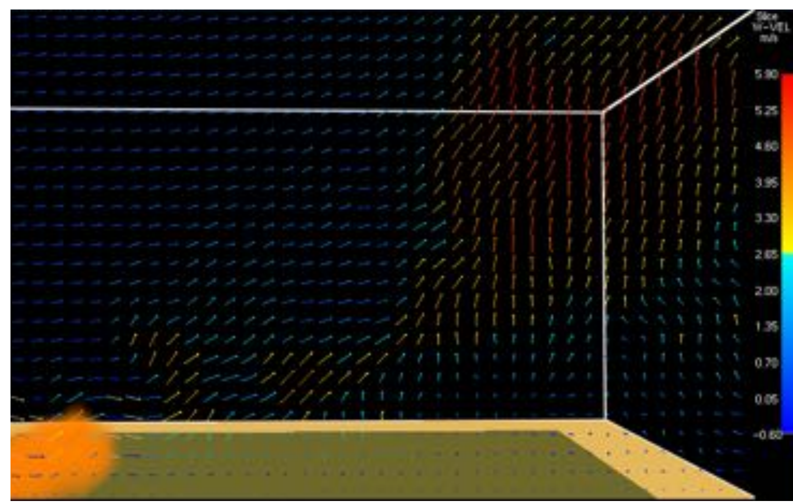
Information available from modeling

•Optimize the resources for fire extinction (fire fighters,canadair).
•Carry out evacuation plans and reduce fire fighters risk.
•Reduce risk and improve effectivness payload delivery.

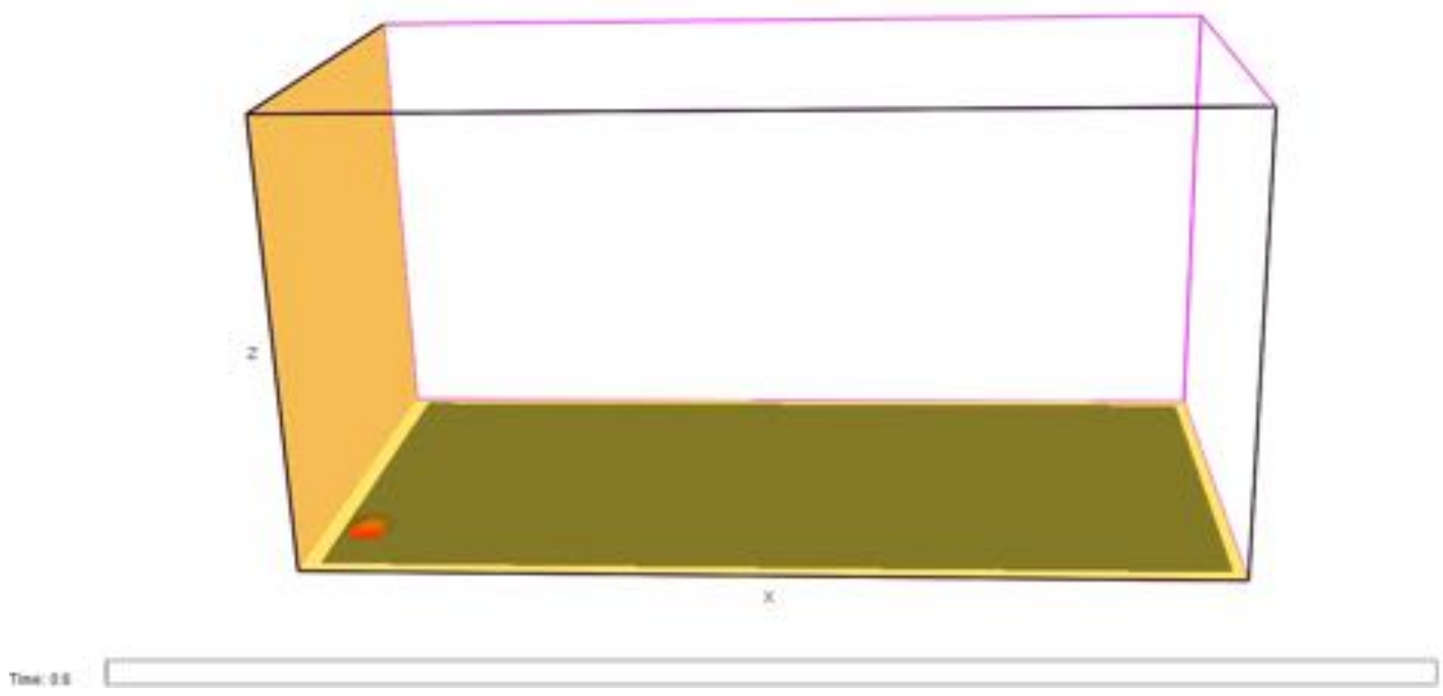
Models for prediction of:

FIRE FRONT EVOLUTION

EFFECTS OF FIRE ON THE SURRONDING ATHMOSPHERE



Physical Models



•PROVIDES LARGE AMOUNT OF INFORMATION

•QUITE ACCURATE IF INPUT IS ACCURATE

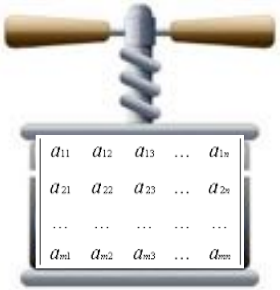
•TOO SLOW AS MANAGEMENT TOOLS

Physical Models

Are there reasonable ways to make wildfire physical models suitable for fast simulations?

An option is

<u>model reduction</u>



Physical Models

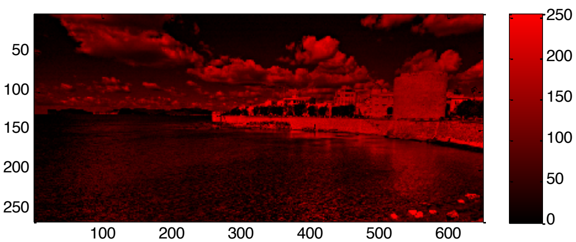
Advanced Forest Firefighting

How much information do we need
in order to obtain the main features of a matrix?

=

COLORED IMAGE =MATRIX
obtained as a sum of
three matrices

$$A = \begin{pmatrix} a_{11} & a_{12} & a_{13} & a_{14} & a_{15} & \cdots\cdots & a_{1n} \\ a_{21} & a_{22} & a_{23} & a_{24} & a_{25} & \cdots\cdots & a_{2n} \\ a_{31} & a_{32} & a_{33} & a_{34} & a_{35} & \cdots\cdots & a_{3n} \\ a_{41} & a_{42} & a_{43} & a_{44} & a_{45} & \cdots\cdots & a_{4n} \\ a_{51} & a_{52} & a_{53} & a_{54} & a_{55} & \cdots\cdots & a_{5n} \\ .. & .. & .. & .. & .. & \cdots\cdots & .. \\ a_{n1} & a_{n2} & a_{n3} & a_{n4} & a_{n5} & \cdots\cdots & a_{nn} \end{pmatrix}$$



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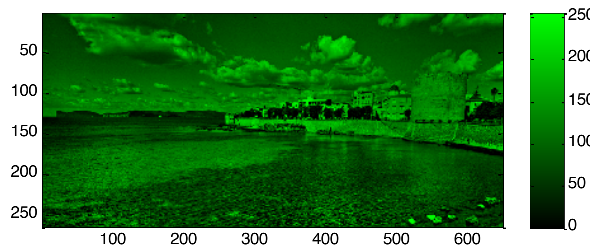

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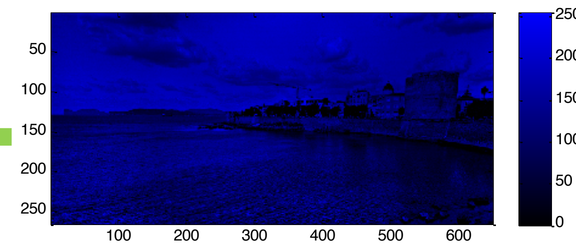


Matrix R

$$A = \begin{pmatrix} a_{11} & a_{12} & a_{13} & a_{14} & a_{15} & \cdots\cdots & a_{1n} \\ a_{21} & a_{22} & a_{23} & a_{24} & a_{25} & \cdots\cdots & a_{2n} \\ a_{31} & a_{32} & a_{33} & a_{34} & a_{35} & \cdots\cdots & a_{3n} \\ a_{41} & a_{42} & a_{43} & a_{44} & a_{45} & \cdots\cdots & a_{4n} \\ a_{51} & a_{52} & a_{53} & a_{54} & a_{55} & \cdots\cdots & a_{5n} \\ .. & .. & .. & .. & .. & \cdots\cdots & .. \\ a_{n1} & a_{n2} & a_{n3} & a_{n4} & a_{n5} & \cdots\cdots & a_{nn} \end{pmatrix}$$

Matrix G

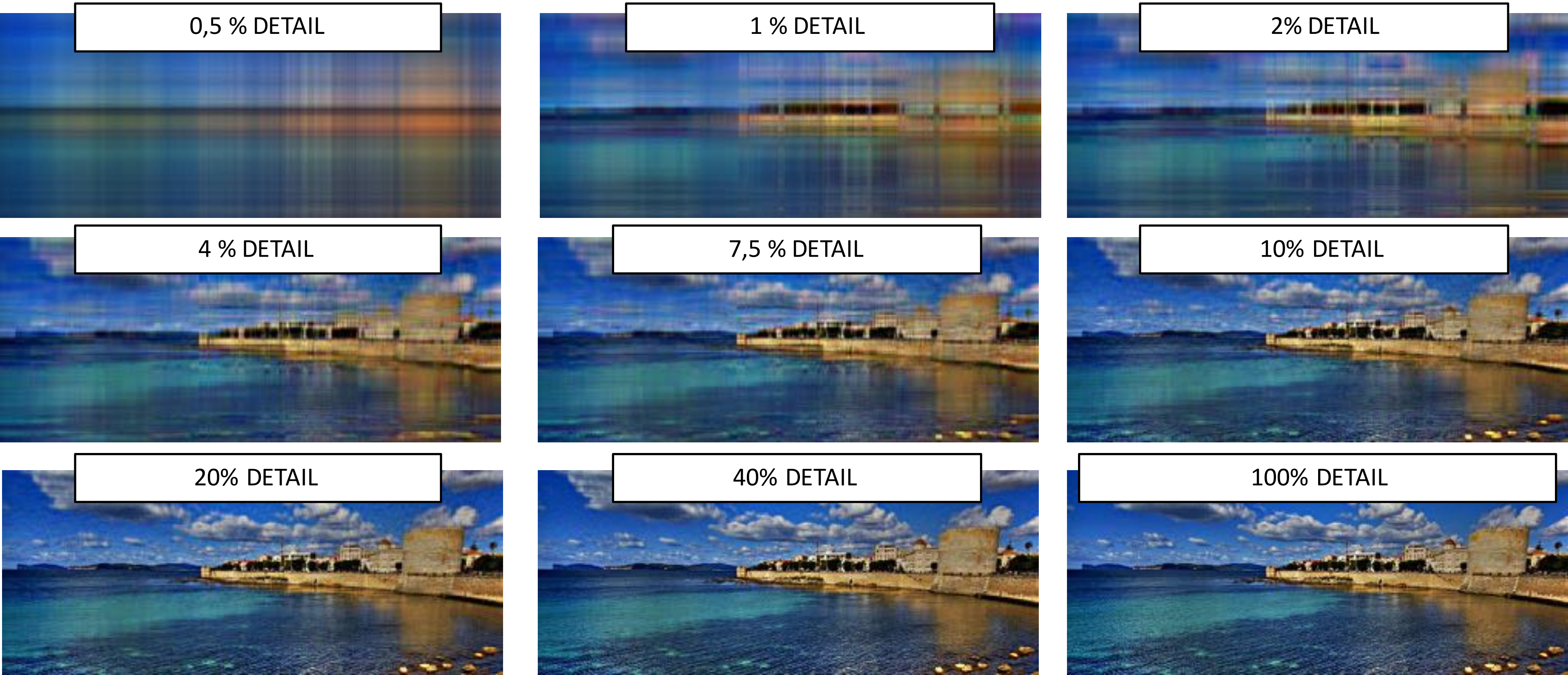
$$A = \begin{pmatrix} a_{11} & a_{12} & a_{13} & a_{14} & a_{15} & \cdots\cdots & a_{1n} \\ a_{21} & a_{22} & a_{23} & a_{24} & a_{25} & \cdots\cdots & a_{2n} \\ a_{31} & a_{32} & a_{33} & a_{34} & a_{35} & \cdots\cdots & a_{3n} \\ a_{41} & a_{42} & a_{43} & a_{44} & a_{45} & \cdots\cdots & a_{4n} \\ a_{51} & a_{52} & a_{53} & a_{54} & a_{55} & \cdots\cdots & a_{5n} \\ .. & .. & .. & .. & .. & \cdots\cdots & .. \\ a_{n1} & a_{n2} & a_{n3} & a_{n4} & a_{n5} & \cdots\cdots & a_{nn} \end{pmatrix}$$

Matrix B

$$A = \begin{pmatrix} a_{11} & a_{12} & a_{13} & a_{14} & a_{15} & \cdots\cdots & a_{1n} \\ a_{21} & a_{22} & a_{23} & a_{24} & a_{25} & \cdots\cdots & a_{2n} \\ a_{31} & a_{32} & a_{33} & a_{34} & a_{35} & \cdots\cdots & a_{3n} \\ a_{41} & a_{42} & a_{43} & a_{44} & a_{45} & \cdots\cdots & a_{4n} \\ a_{51} & a_{52} & a_{53} & a_{54} & a_{55} & \cdots\cdots & a_{5n} \\ .. & .. & .. & .. & .. & \cdots\cdots & .. \\ a_{n1} & a_{n2} & a_{n3} & a_{n4} & a_{n5} & \cdots\cdots & a_{nn} \end{pmatrix}$$

Reduced Physical Models

How much information do we need
in order to obtain the main features of a matrix?



Reduced Physical Models

Full model

$$C\dot{T} = AT + DT^4 + f$$

N equations

SET OF RESULTS

$$\begin{pmatrix} T_1^{t=1} & T_1^{t=2} & \dots & T_1^{t=end} \\ T_2^{t=1} & T_2^{t=2} & \dots & T_2^{t=end} \\ \dots & \dots & \dots & T_3^{t=end} \\ T_{end}^{t=1} & T_{end}^{t=2} & \dots & T_4^{t=end} \end{pmatrix}$$

POD

$$T(x,t) \cong \widetilde{B}(x)\widetilde{\alpha}(t)$$

REDUCED MATRICES

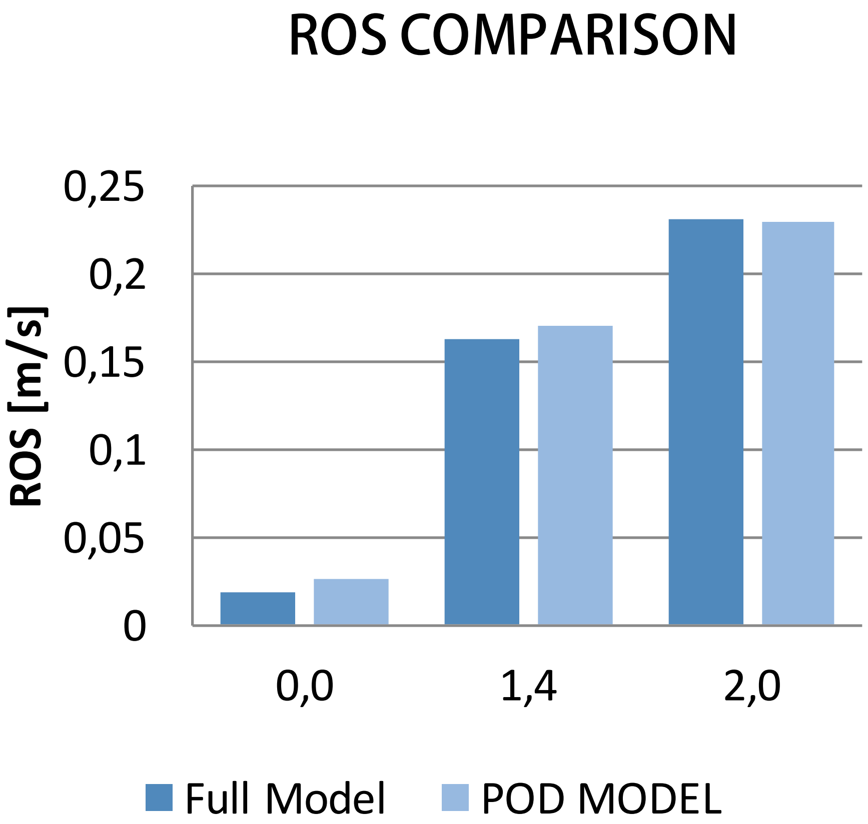
Reduced model

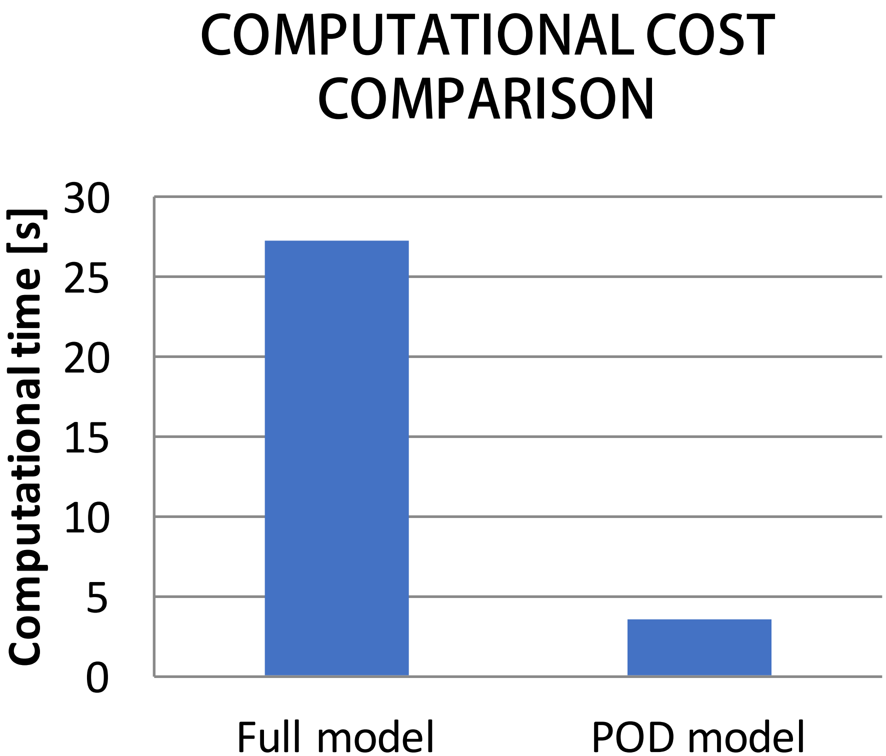
$$\widetilde{C}\dot{\alpha} = \widetilde{A}\alpha + B^T D(B\alpha)^4 + B^T f$$

K equations with K<<N

- 85% of the computational cost

Reduced Physical Models





Summary

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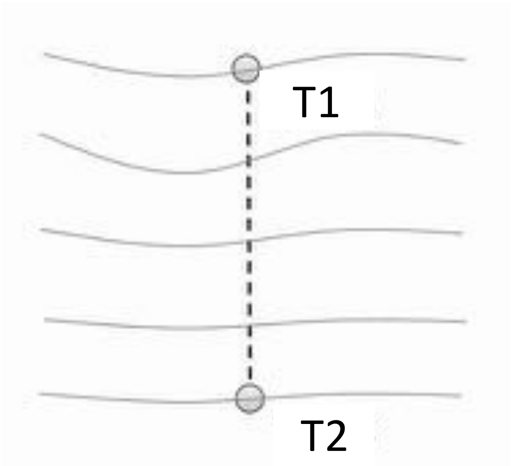
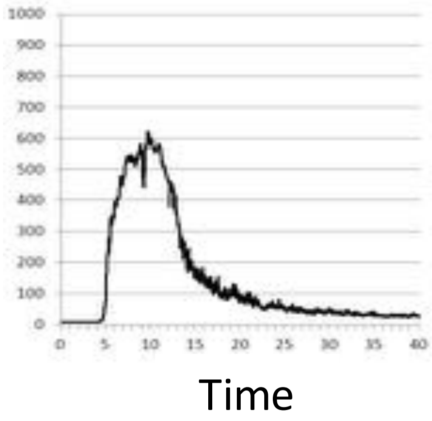
What to measure?

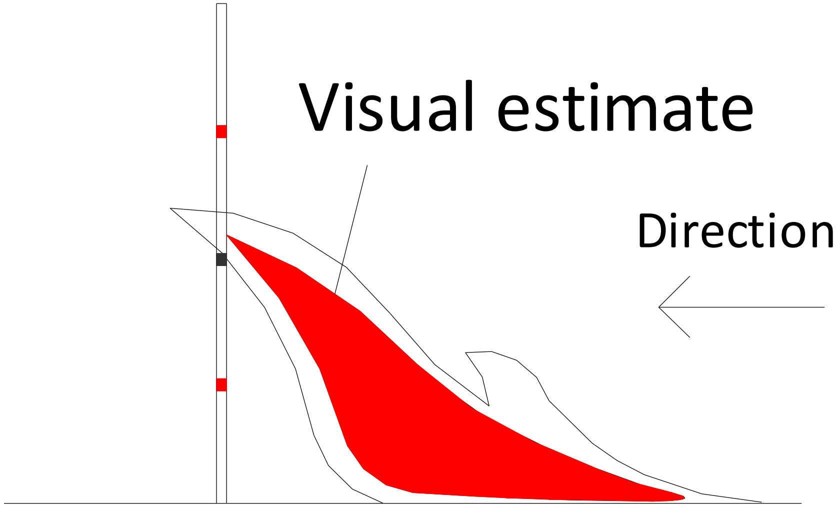
Fire descriptors

- Flame length (m)
- Rate of spread head, back, flank of the fire front (m/min)
- Fireline intensity (kW/m)
- Fire temperature (°C)
- Radiant energy fluxes (kW/m^2)



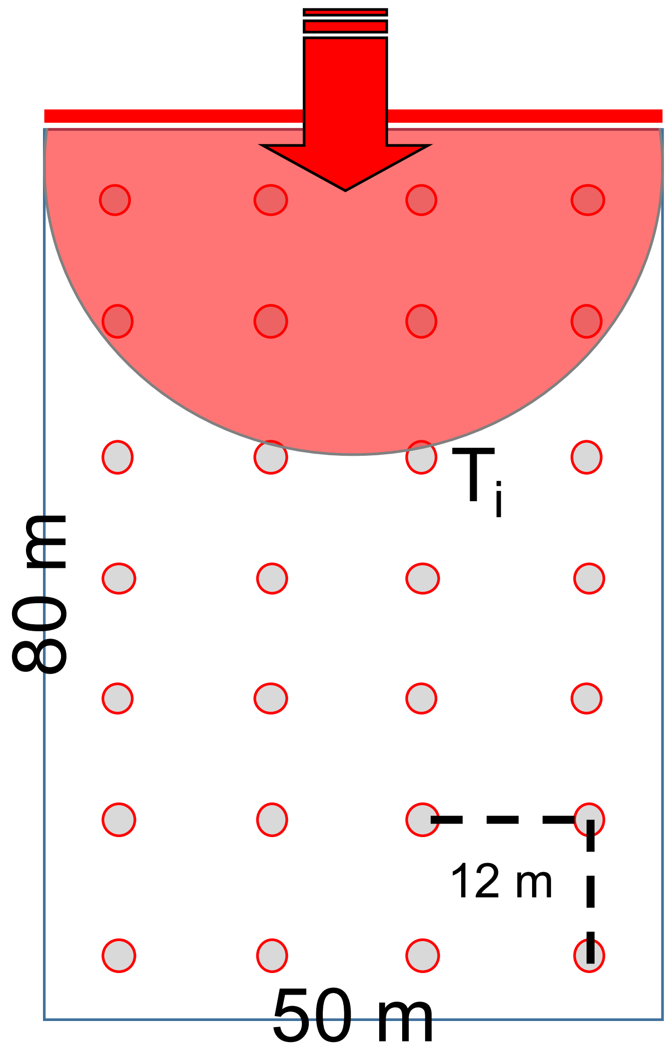


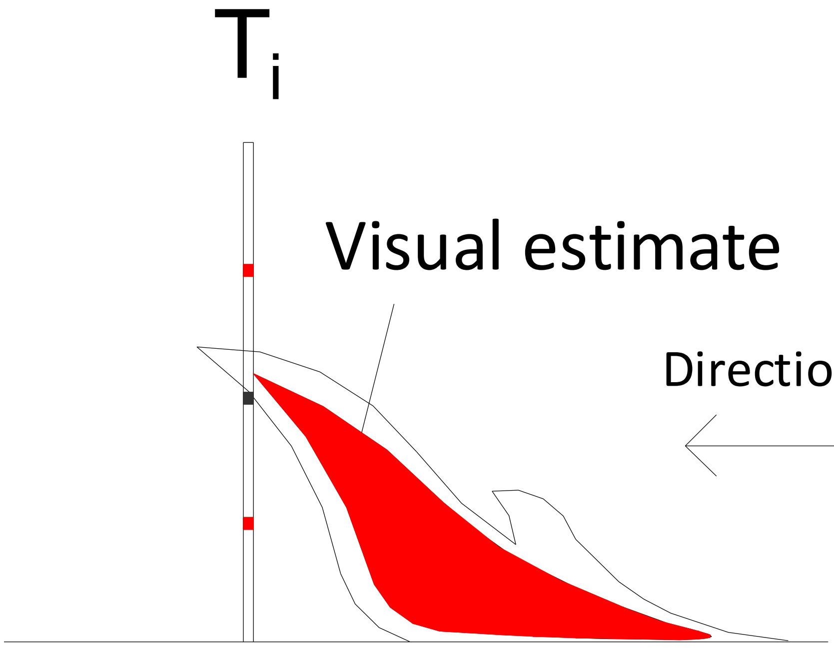
Flame length



Flame length is the distance from the **average flame tip** to the **middle of the flaming zone** at the base of the fire.

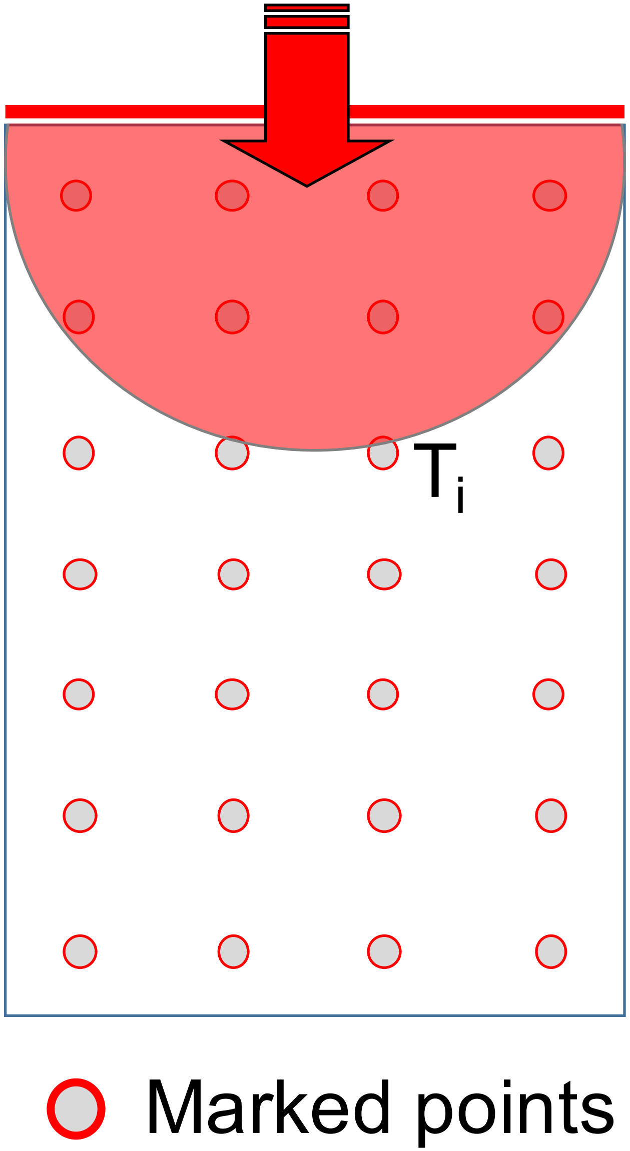
Rate of spread: visual estimate

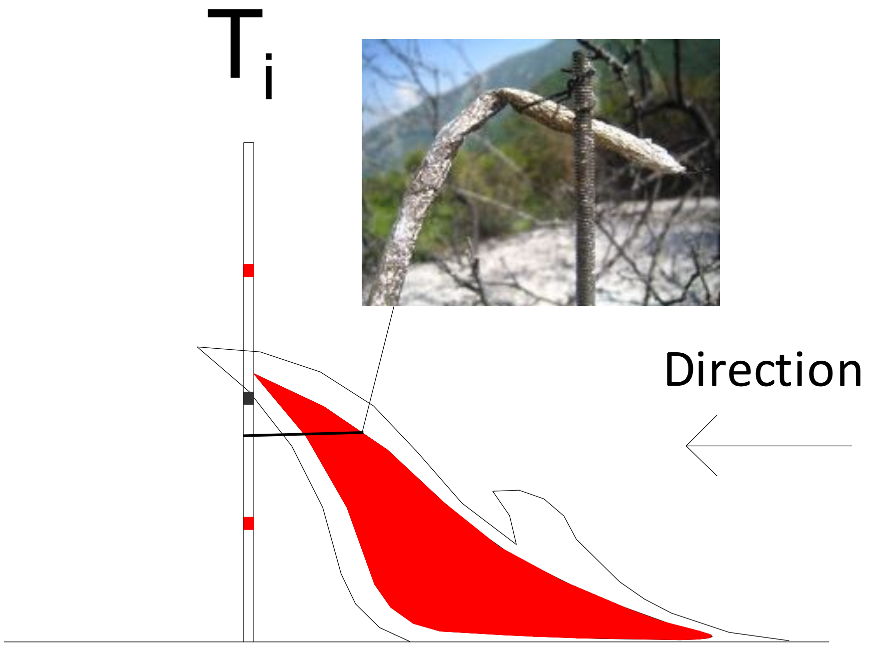


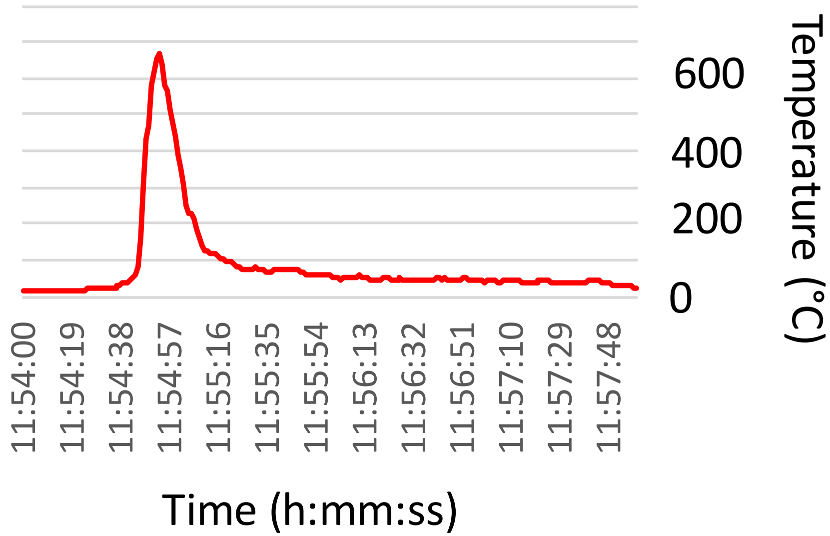


Marked points

Rate of spread: thermocouples







Temperature and heat flux

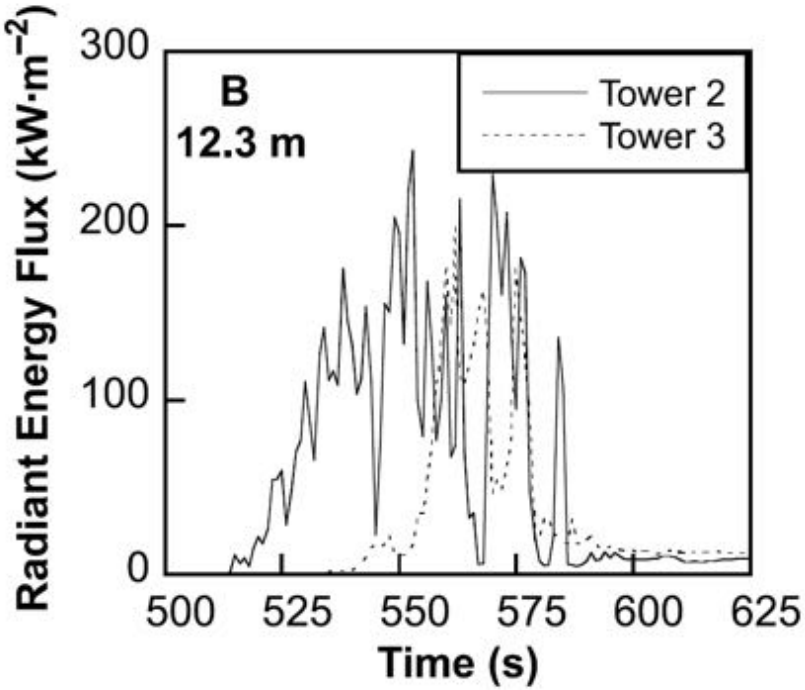
Heat flux-meter

Thermocouple

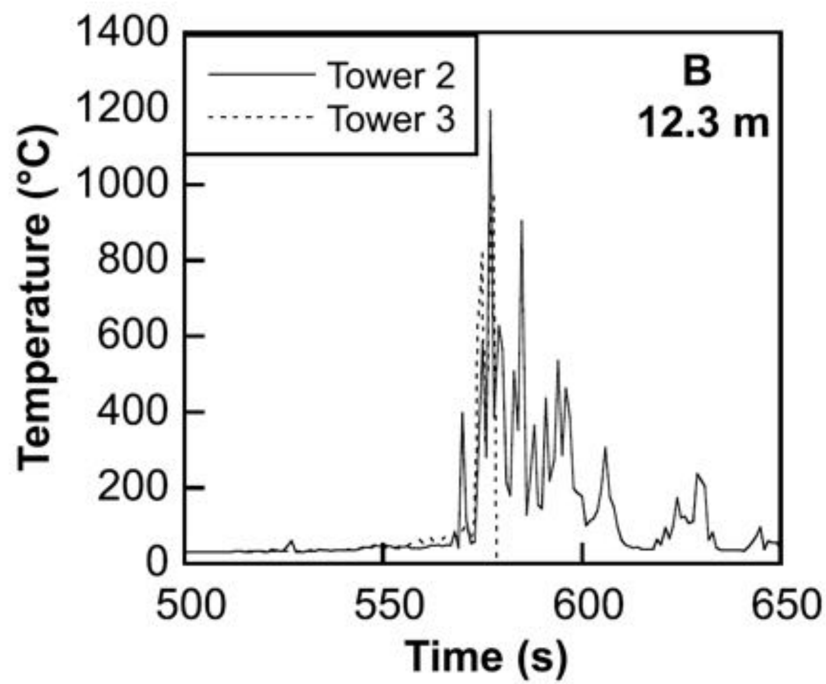
Data-logger

Source: Frédéric Morandini et Xavier Silvani

Temperature and heat flux



Butler B.W. et al. 2004
Measurements of radiant emissive power and temperatures in crown fires
Canadian Journal of Forest Research
34(8): 1577-1587



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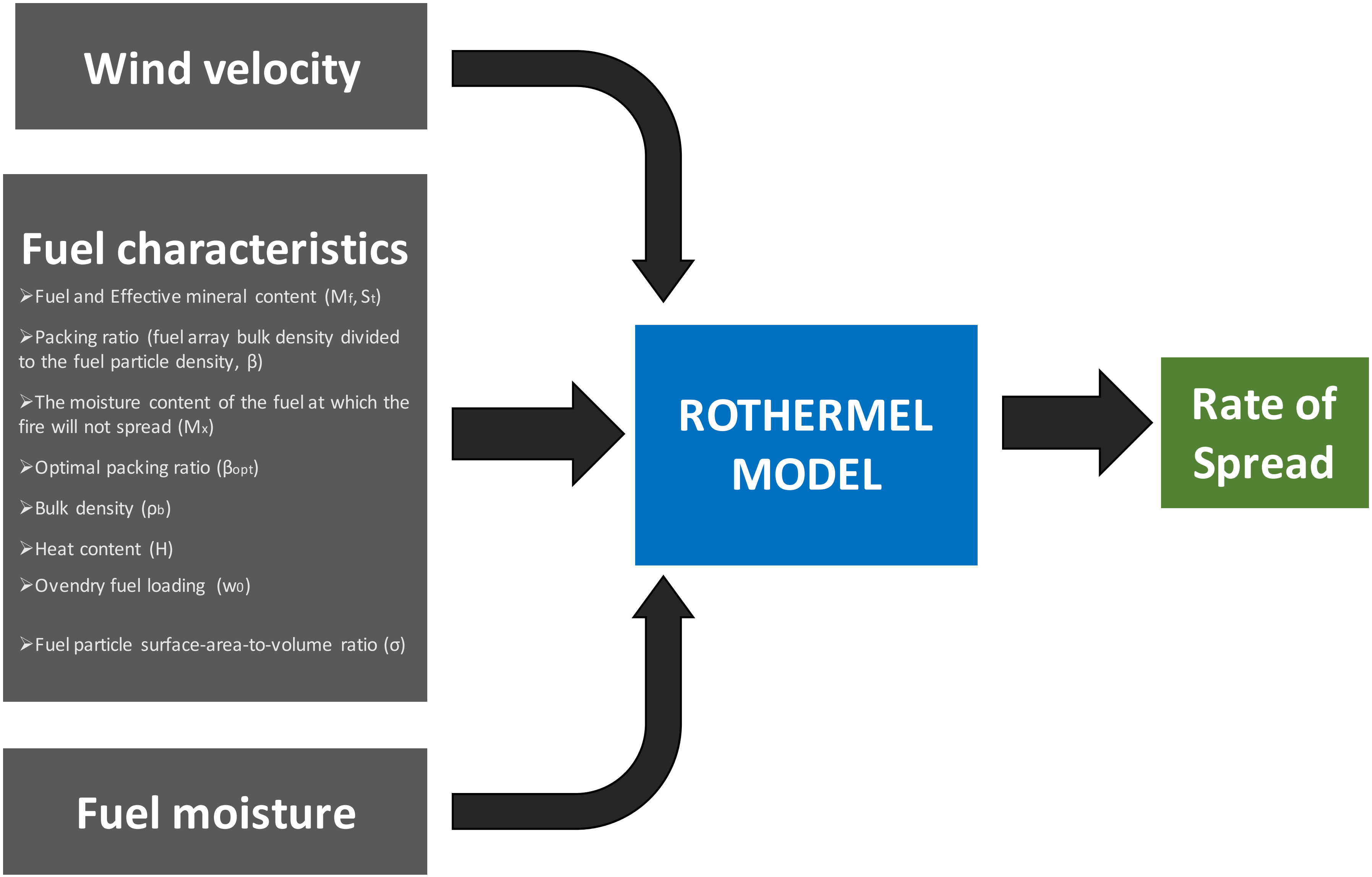
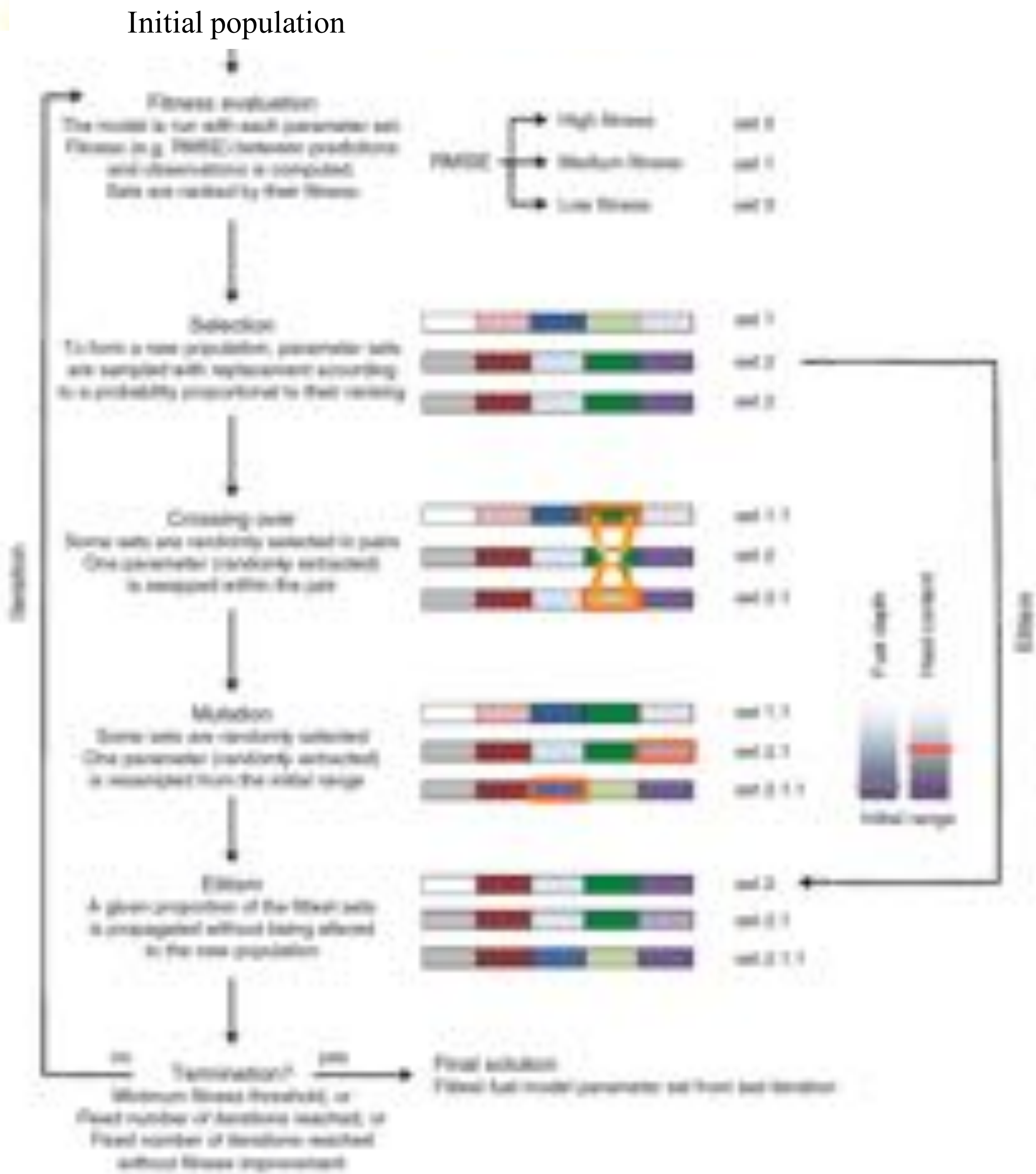
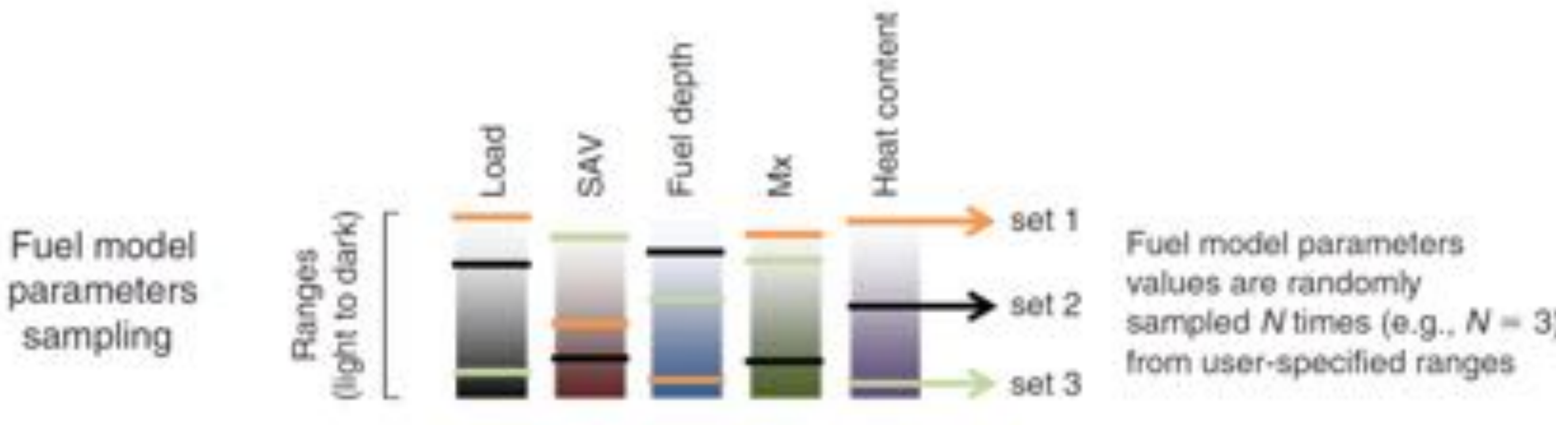
Rothermel model



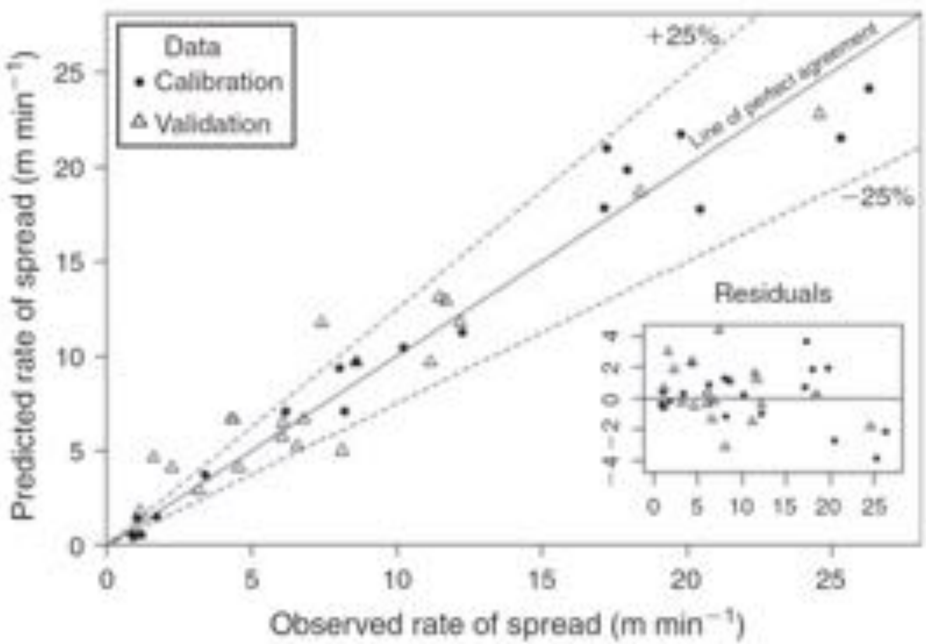
Genetic algorithm



GA for fuel model



Results



Data
Calibration
Validation
+25%
Line of perfect agreement
−25%
Residuals
Predicted rate of spread (m min⁻¹)
Observed rate of spread (m min⁻¹)
0
5
10
15
20
25

Results

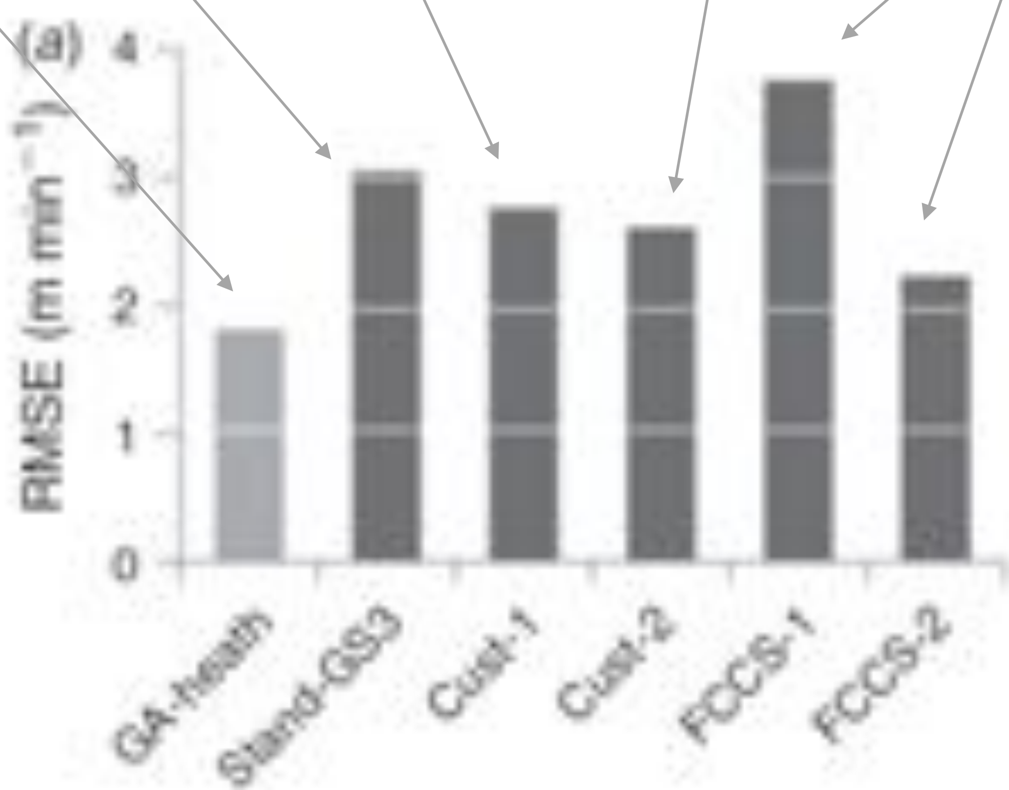
Rothermel calibrated using GA optimisation

Standard Rothermel fuel model

custom fuel model parameterised by averaging fuel characteristics

Site-specific custom fuel model parameterised by averaging fuel loadings and structure measured at each fire site

Rothermel model reformulation that is implemented in the Fuel Characteristics Classification System (Sandberg *et al.* 2007; Prichard *et al.* 2013).



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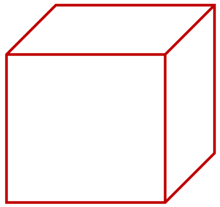
1D physical model



ENERGY AND MASS CONSERVATION EQUATION APPLIED TO A CONTROL VOLUME

$$\rho c \frac{\partial T}{\partial t} + k_v v \frac{\partial T}{\partial x} = k \frac{\partial^2 T}{\partial x^2} - h(T - T_e) - \frac{H}{s}\frac{dM}{dt} + \Phi_{RAD}$$

$$\frac{dM}{dt} = -aM$$

$$\Phi_{RAD} = \sum_j r F_{ij} \varepsilon \sigma \left(T_j^4 - T^4\right)$$

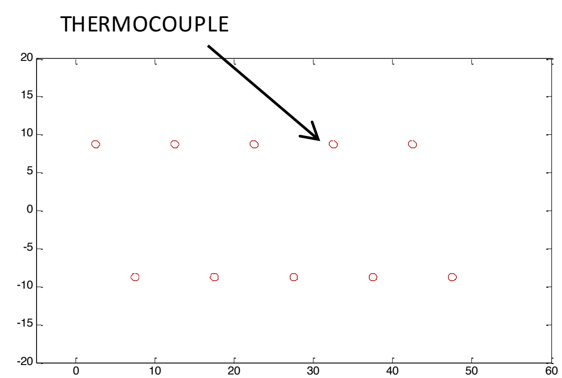
Symbol	Explanation	Evaluation
P	Mixture air fuel density	Laboratory Analysis
C	Specific heat	(Campbell, Norman 2012)
k_v	Advective coefficient	GA using Thermocouple Measurements
K	Diffusive coefficient	GA using Thermocouple Measurements
h	Losses coefficient	GA using Thermocouple Measurements
H	Energy content	Laboratory Analysis
S	Fuel height	Field Analysis
A	Mass rate variation coefficient	GA using Thermocouple Measurements
R	Radiative coefficient	GA using Thermocouple Measurements

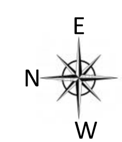
Experimental data

- 4 Field experiment are carried out in different wind conditions

- Dead fully cured grasses (diameter< 6 mm). From laboratory and field analysis:

- Load 0,43 kg/m2
- Height 10 cm
- Packing Ratio 0,002
- Burned biomass 0,39 kg/m2
- Bulk density 5 kg/m3
- Heat power of fuel 18,5 MJ/kg
- Humidity 11% of dry fraction



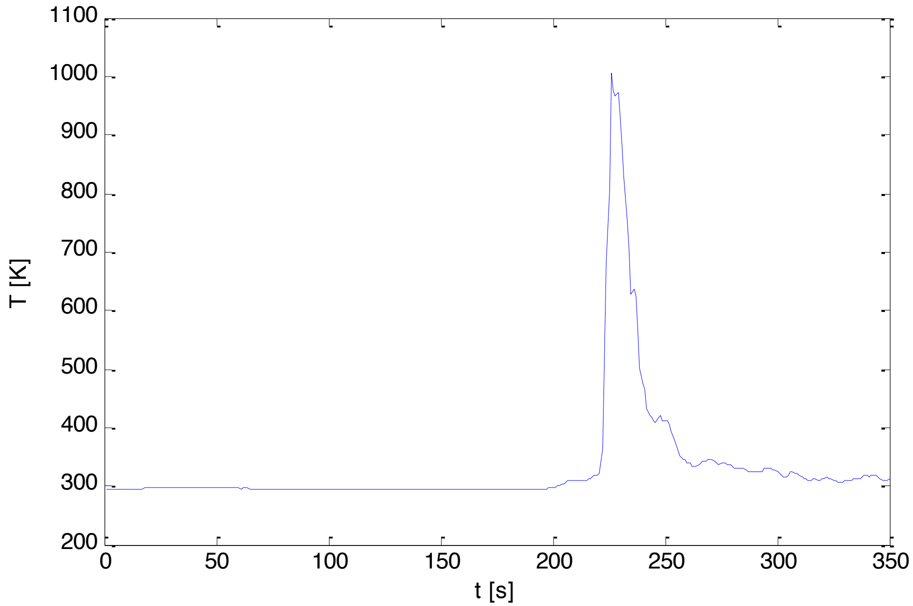


- Wind velocity and direction data are collected every 10 s

- Thermocouples detect temperature evolution during each experiment

Model calibration through experimental data

AF3 Advanced Forest Firefighting



$$Err = w_1 * Err_{maxT} + w_2 * Err_{integral} + w_3 * Err_{arrive} + w_4 * Err_{burning}$$

Symbol	Explanation	Evaluation
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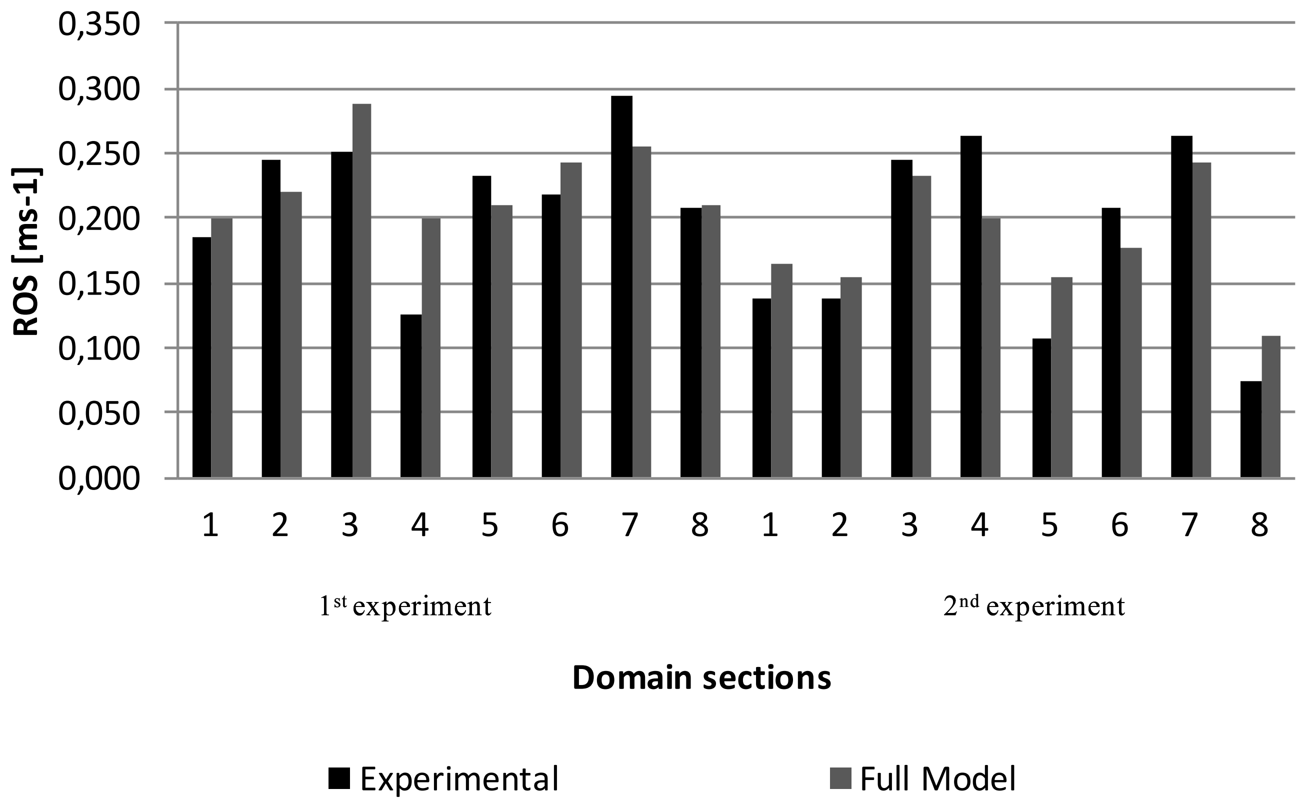
Model calibration through experimental data



Thank you for the attention

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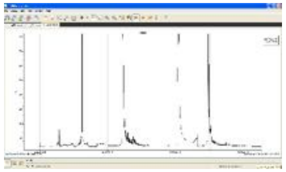
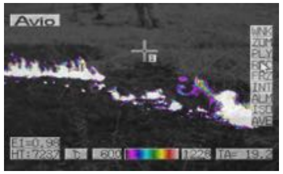
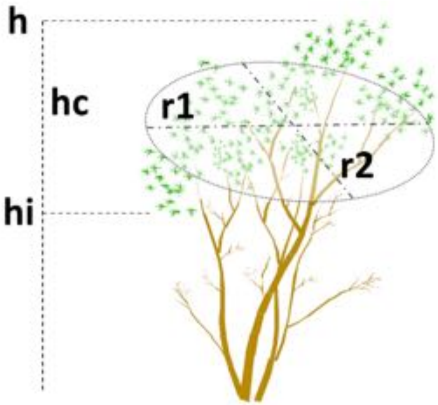



What to measure?

Fire environment

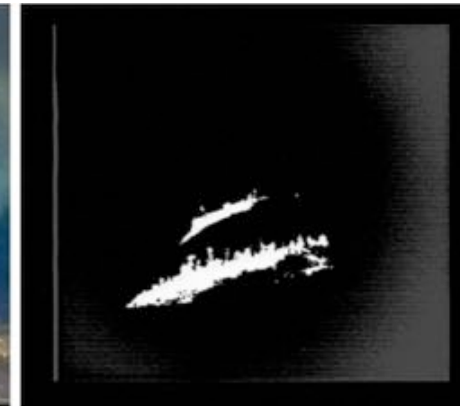
- Fuel structural characteristics: direct-indirect
- Fuel moisture: direct-indirect (eg fire danger index)
- Wind field (direction, speed)
- Air temperature – relative humidity
- Orography (slope, aspect, elevation)



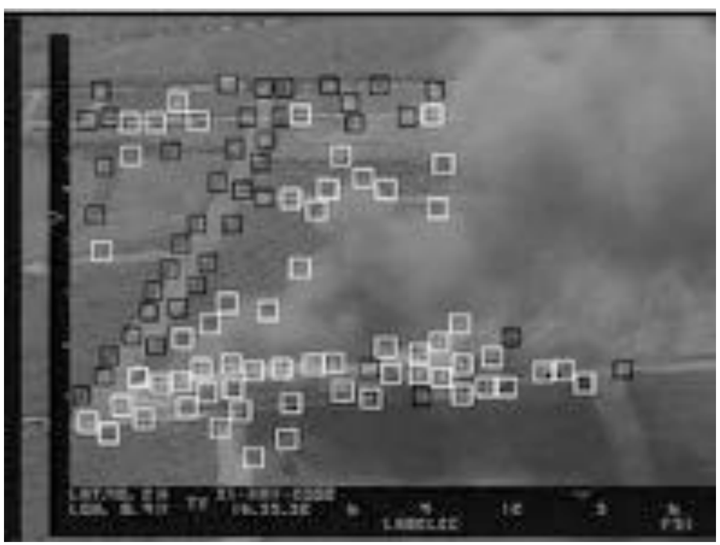
Rate of spread: photos

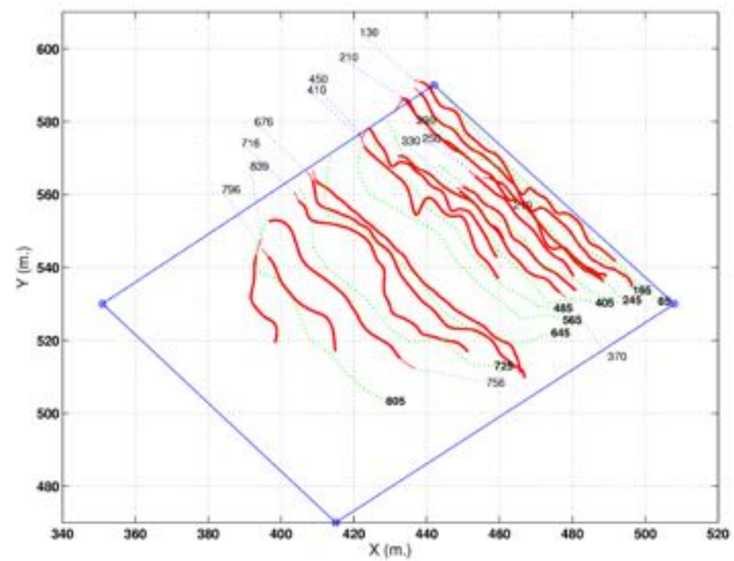
Exp. 7 – M1.3

Rate of spread: IR techniques

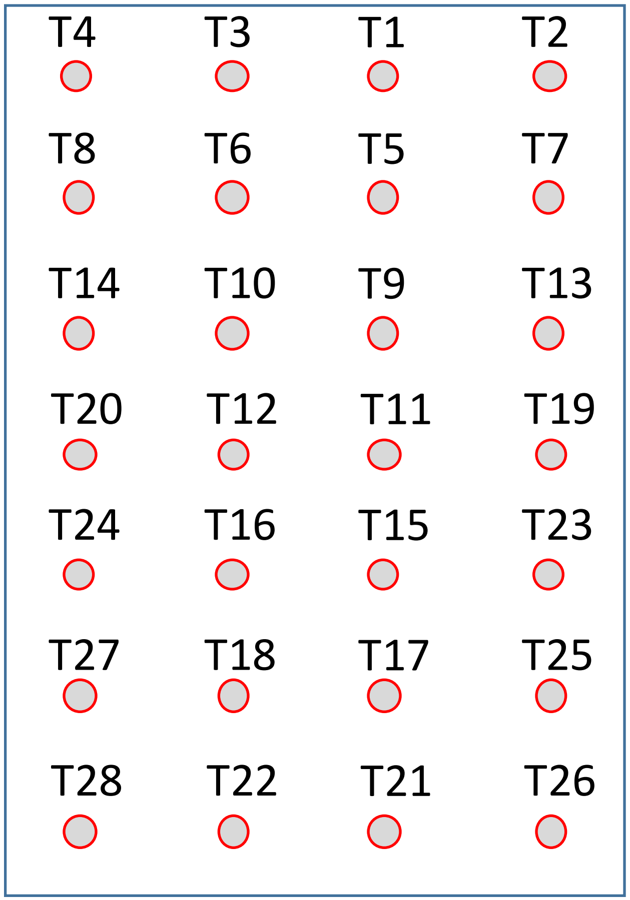


Martinez-de-Dios et al. 2011

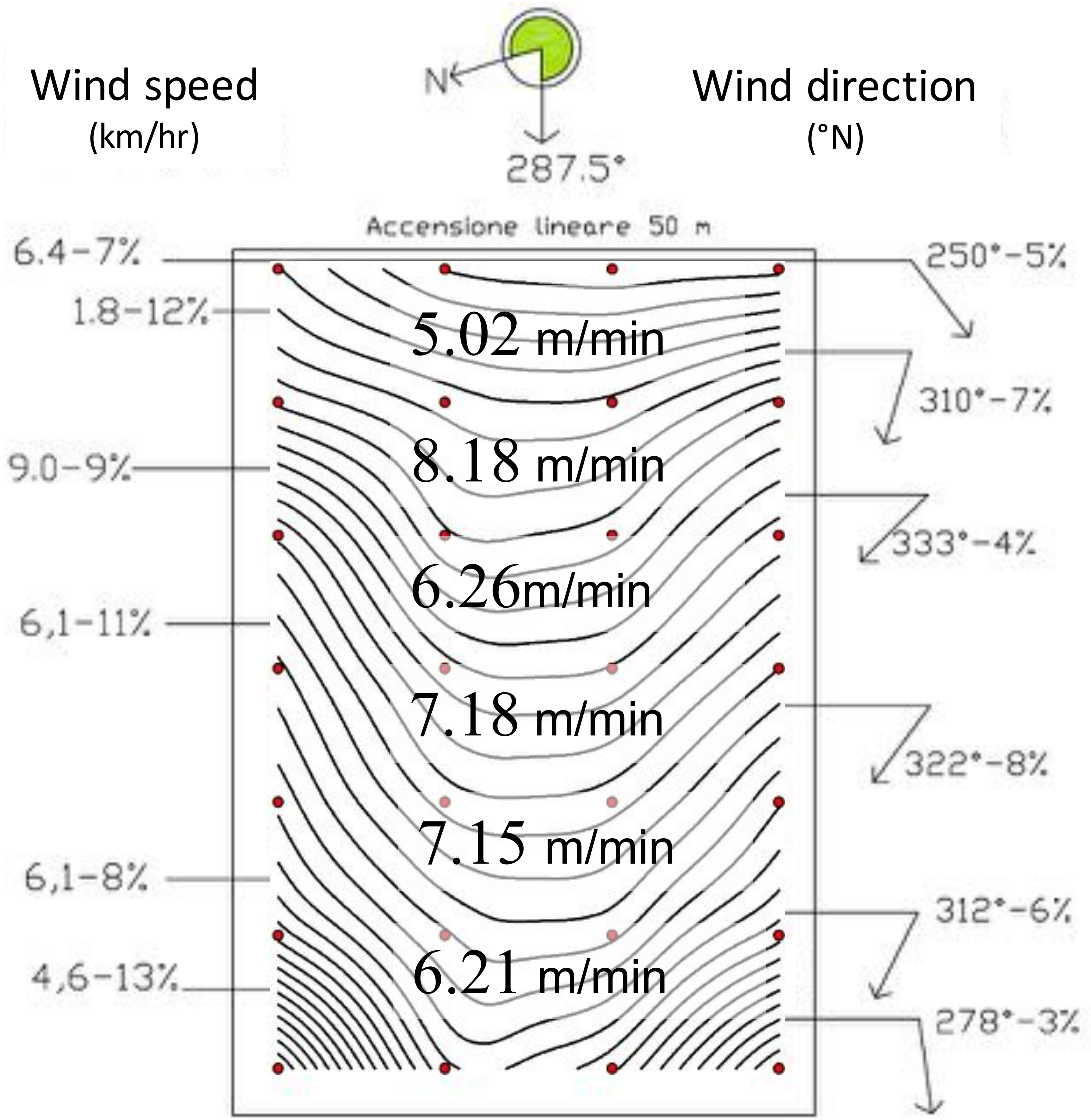


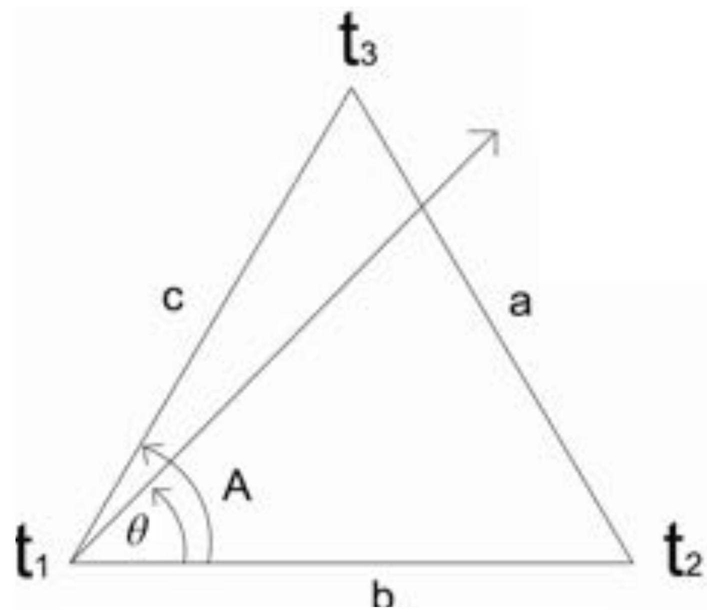


Rate of spread



Rate of spread





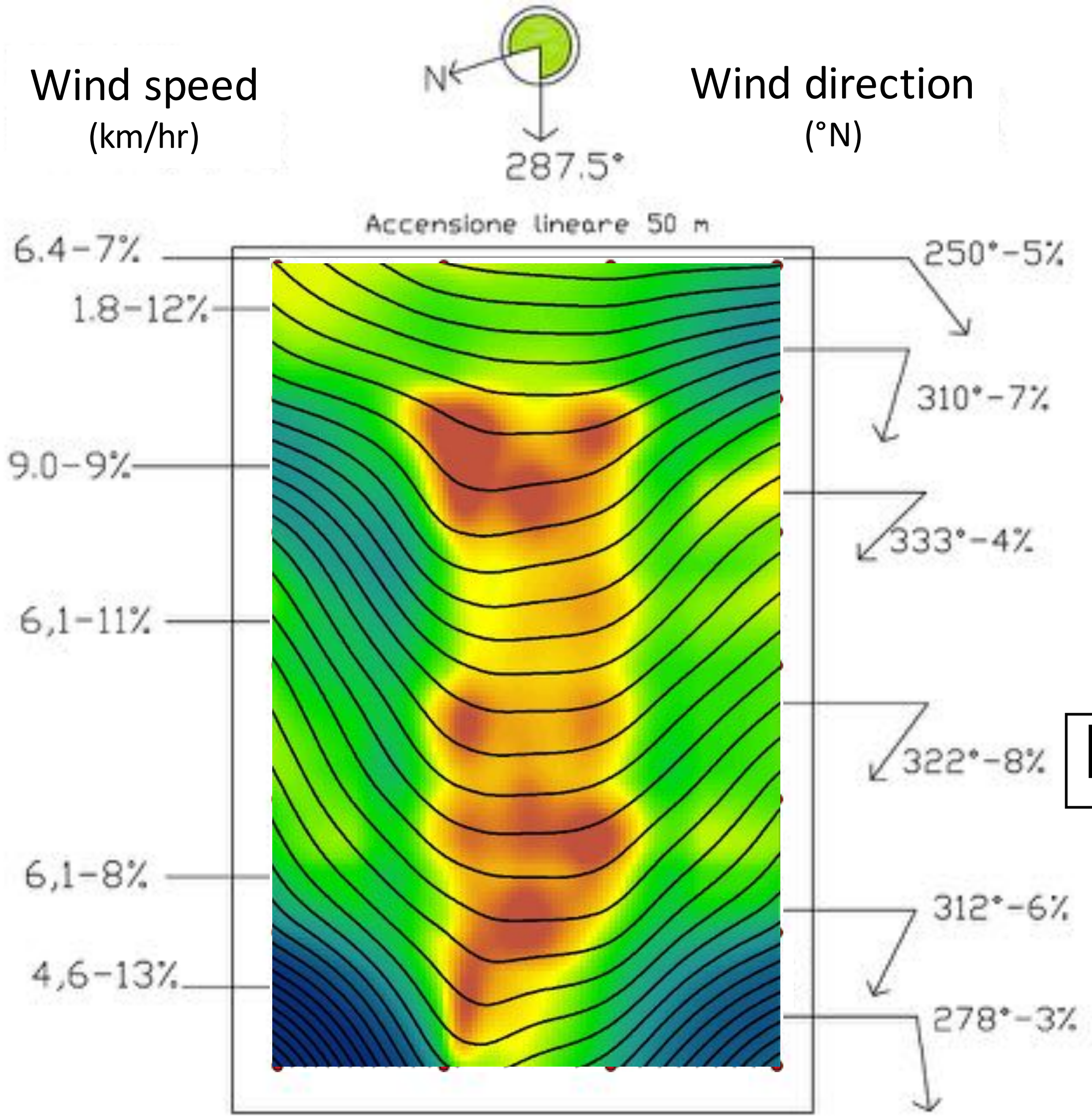
Fire Front Direction

$$\Theta = \tan^{-1}\left[\left(\frac{t_3-t_1}{t_2-t_1}\right)\left(\frac{b}{c\sin A}\right)-\frac{1}{\tan A}\right]$$

Fire Rate of Spread

$$V=\frac{b\cos\theta}{t_2-t_1}$$

Fireline intensity



Fuel samples

PRE - POST = W $(kg\ m^{-2})$

W = fuel comsumed

X

ROS $(m\ s^{-1})$

X

H = $18*10^3$ $kj\ kg^{-1}$ heat content

$I_{(kW\ m^{-1})} = ROS \times W \times H$

Byram (1959)