Fire Front Dynamics Similitude At Small and Large Scales

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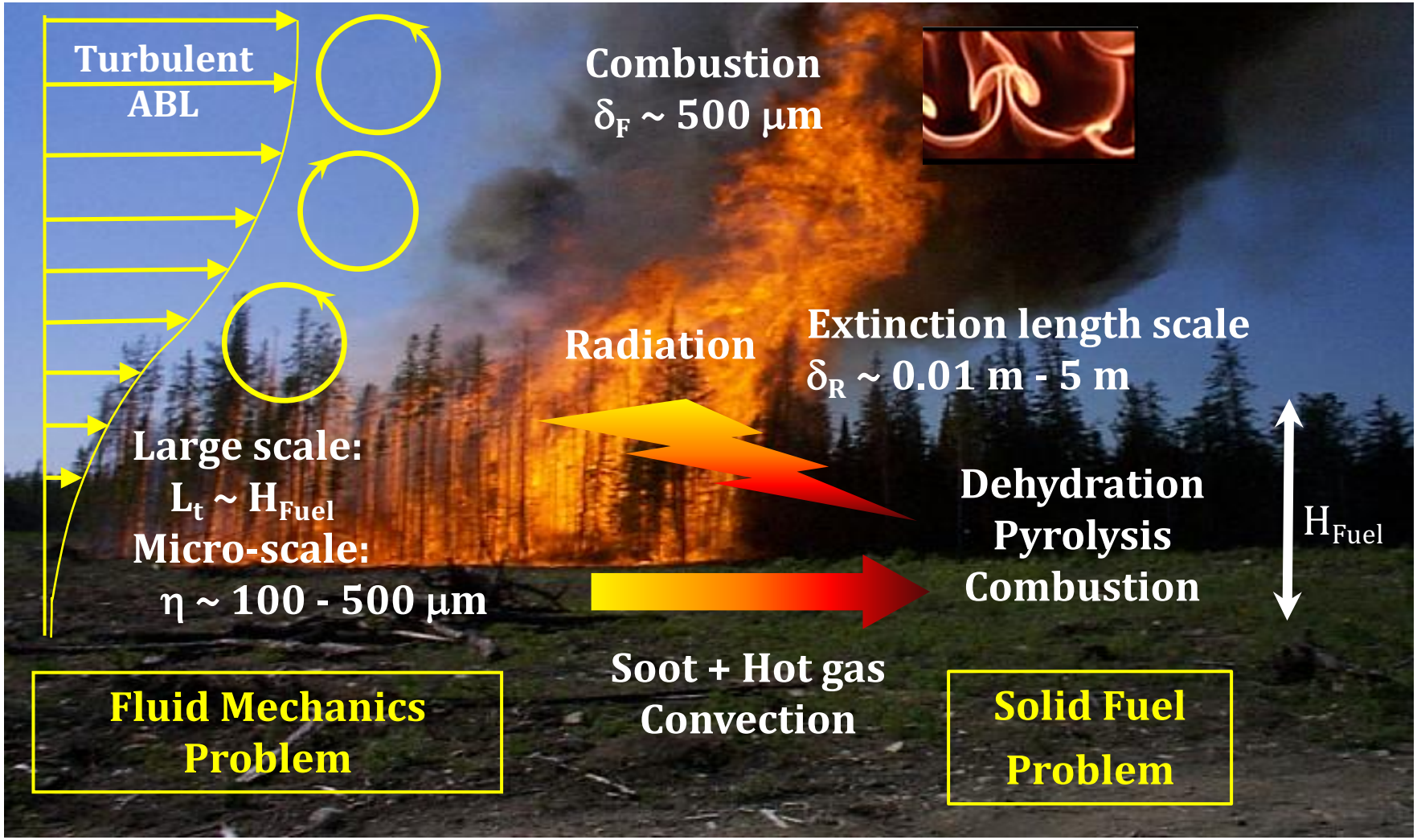
"Fully" Physical Model for Wildfires Simulation



Morvan, Fire Technology 2011

FireStar3D Model

❑ Gaseous Phase

- ➢ Low Mach number formulation (Navier-Stokes equations)
- ➢ Turbulence: k-ε and LES approaches
- ➢ Heat Transfer: Enthalpy formulation + Radiation (RTE)
- ➢ Species: Transport + Combustion in fluid phase (EDC model)
- ➢ Soot: Transport equation + Oxidation

❑ Solid Particles

- ➢ Drying, Pyrolysis & Combustion models
- ➢ Mass, energy and particle size balances

❑ Gaseous Phase/Solid coupling

- ➢ Aerodynamics (porous media)
- ➢ Heat transfer
- ➢ Species exchange

Numerical Approach

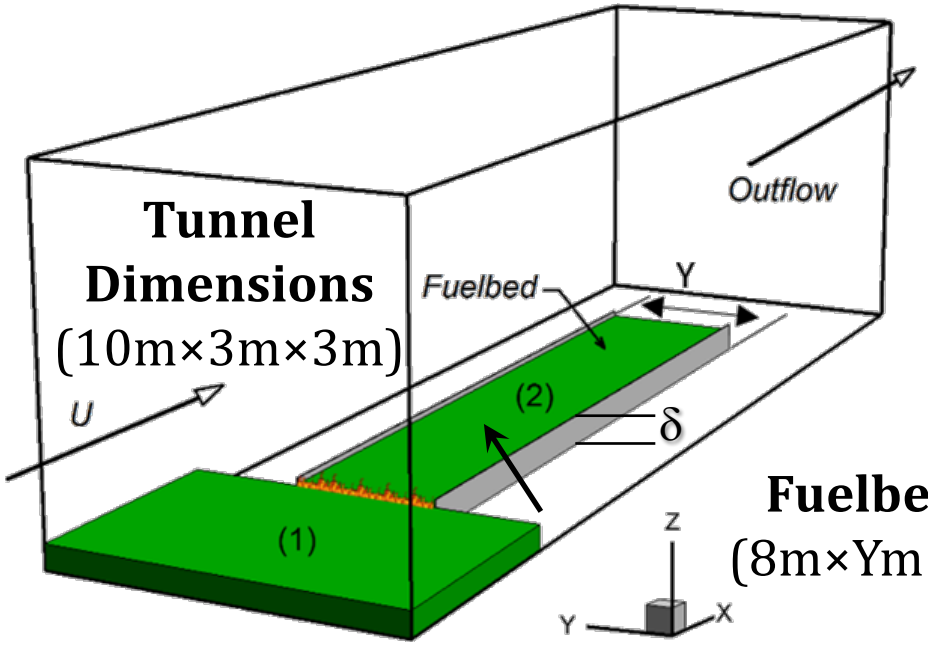
- **Formulation**
  - Fully Implicit (Non-conditional temporal stability)
  - Segregated Formulation (PISO algorithm)
- **Numerical Method**
  - Finite Volume Method on Cartesian non-uniform grid
  - Solid phase is solved by a 4^{th} order Runge-Kutta method.
  - 2^{rd} order space accuracy
  - 3^{rd} order time precision with Adaptive time-stepping
- **Radiation:** Discrete Ordinate Method (DOM)
- **Parallel Computing:** OpenMP directives

Wind-Tunnel Fires

- Rate of Spread
- Fire-front wave number
- Flames fluctuation

Missoula Laboratory

Mark Finney Experiments



Fuelbed (8m×Ym×δ)

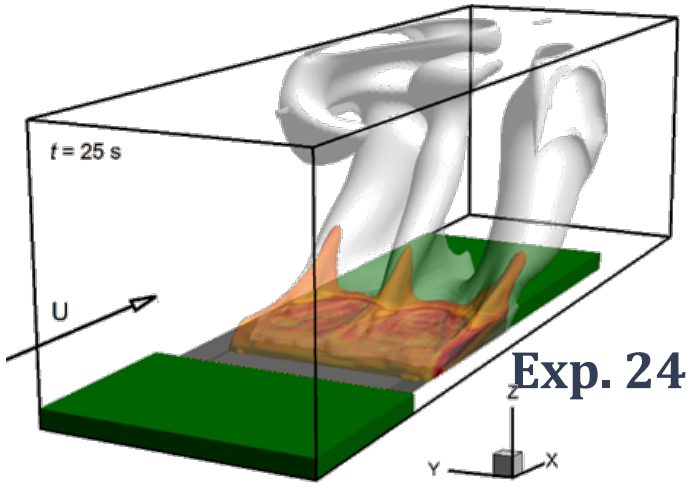
For 6 Experiments:

Fuelbed:
α_s = 0.0038 - 0.0089
Y = 1.22 - 2.45 m

Wind speed:
U = 0.22 - 0.89 m/s

Fire front structure

Mark Finney in 2013

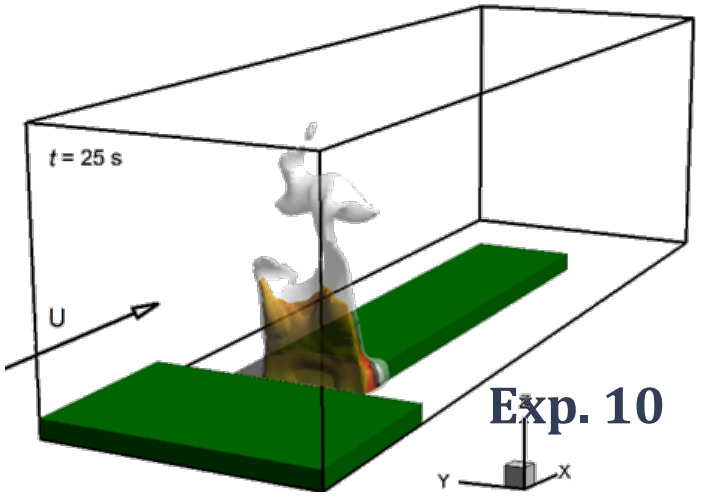


➢ Rate of spread

Exp.	10	18	19	24	25	26
ROS (m/s)-EXP.	0.0119	0.029	0.054	0.107	0.088	0.066
ROS (m/s)-SIM.	0.035	0.038	0.050	0.111	0.087	0.081

➢ Wave number

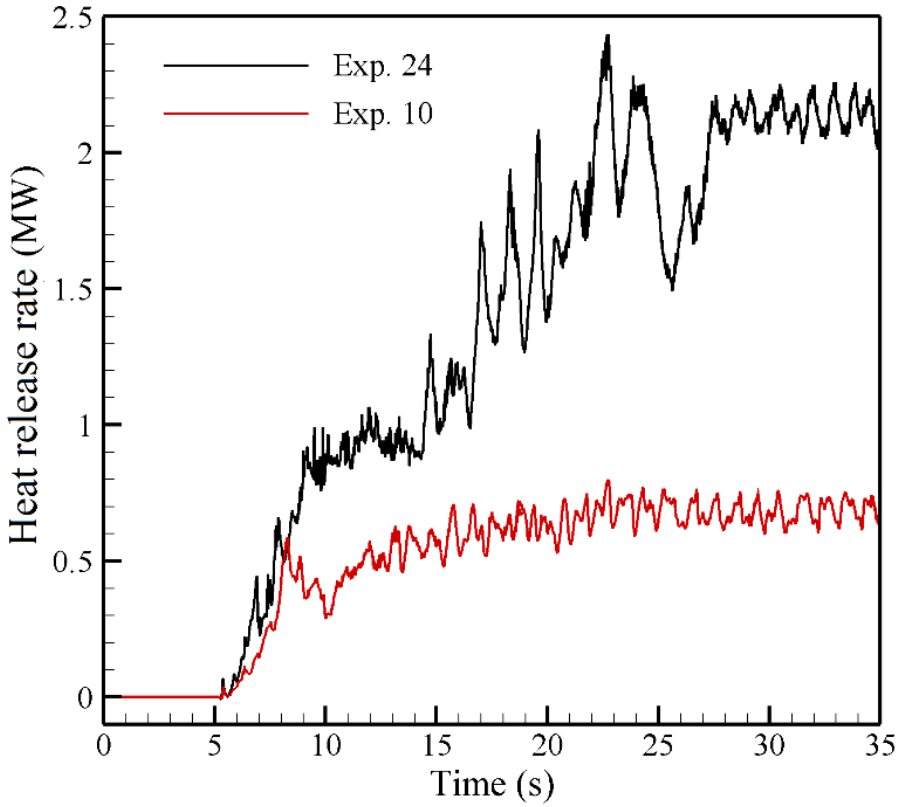
Exp.	10	18	19	24	25	26
w_δ – Exp.	3	3	2	2	3	4
w_δ – Sim.	1	2	2	2	3	3



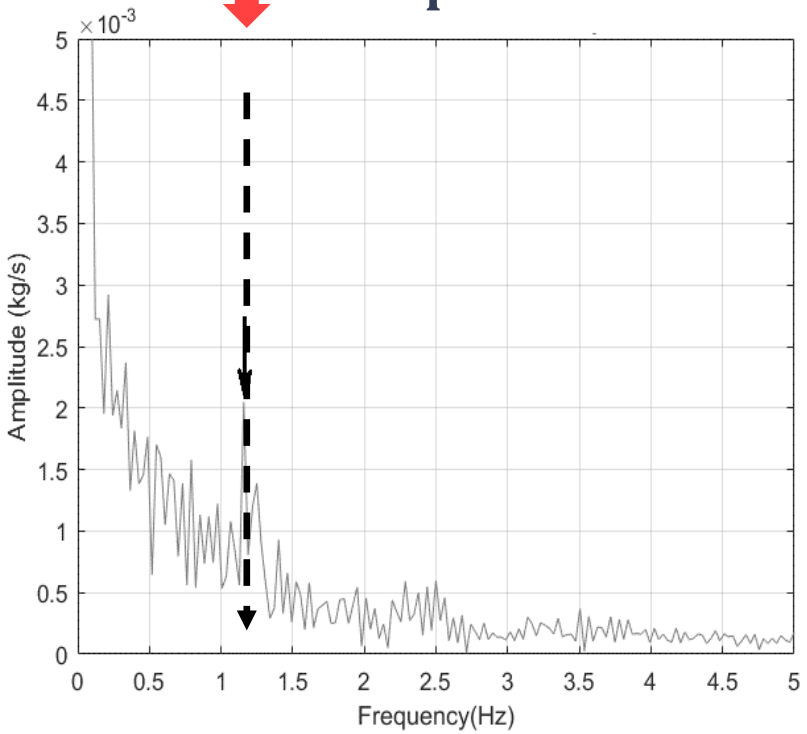
Flames fluctuation

Exp.	10	18	19	24	25	26
f(Hz)–Exp.	1.269	1.195	1.643	1.350	2.449	1.162
f(Hz)–Sim.	1.084	1.258	1.600	1.252	1.760	1.070

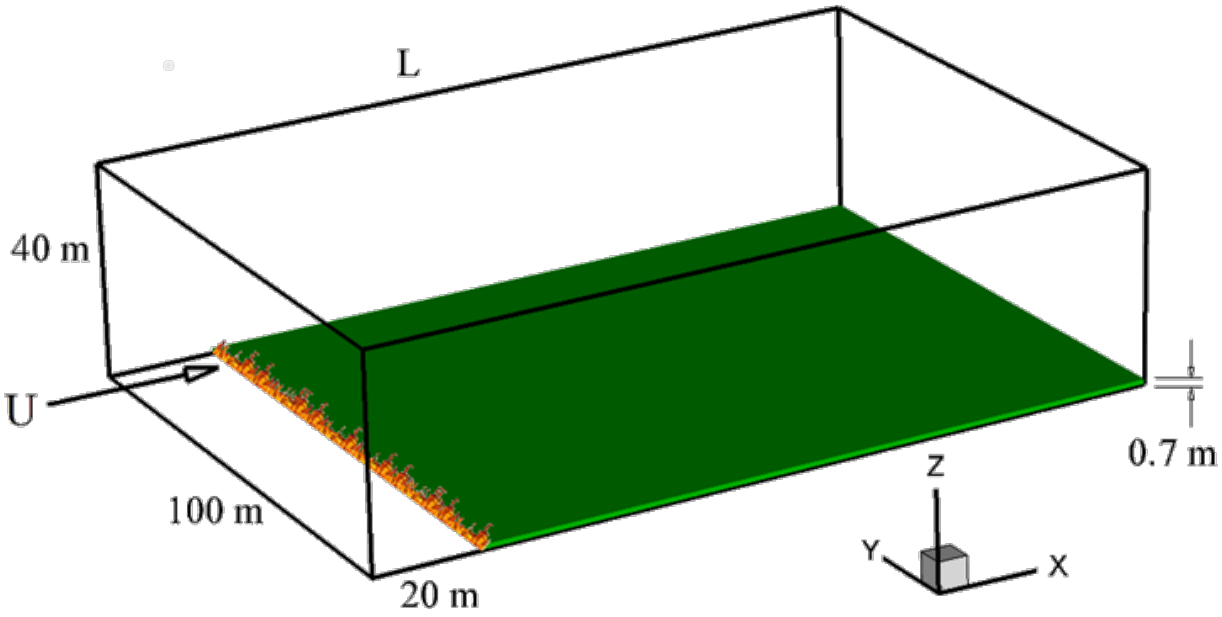
Frequency
k = 1.252 Hz



Exp. 24



Grassland Fires: Quasi-Infinite Fireline



-Wind speed = 1 – 16 m/s

-Packing ratio: α = 0.002

-Fuel bed: δ = 0.7 m

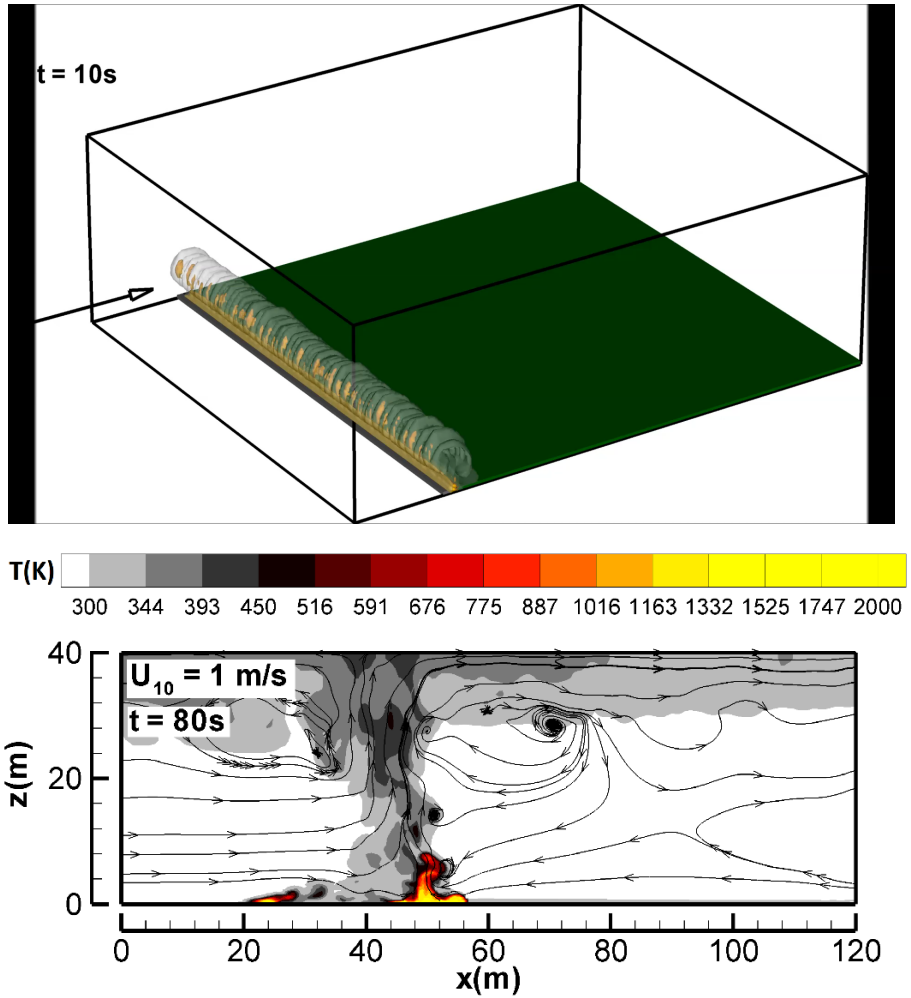
-Fuel density: ρ_P = 500 kg/m^3

-Surface/Volume ratio: σ = 4000 m^{-1}

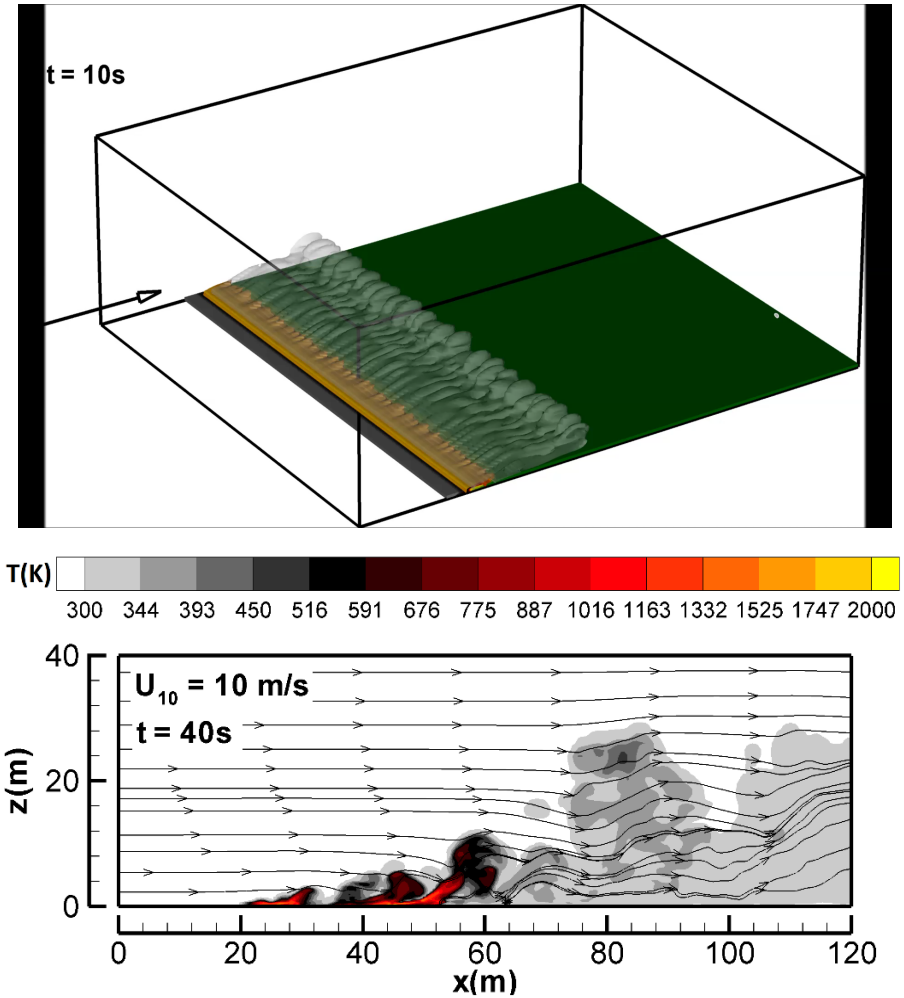
-Moisture content: M = 5 %

Fire regimes

$U = 1$ m/s

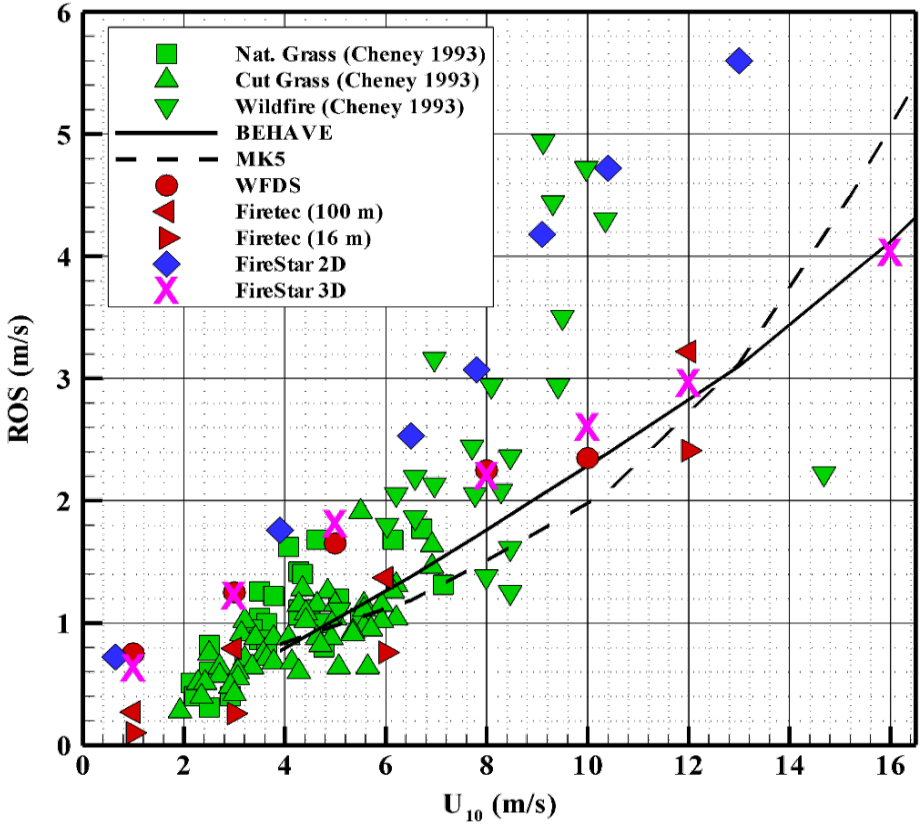


$U = 10$ m/s

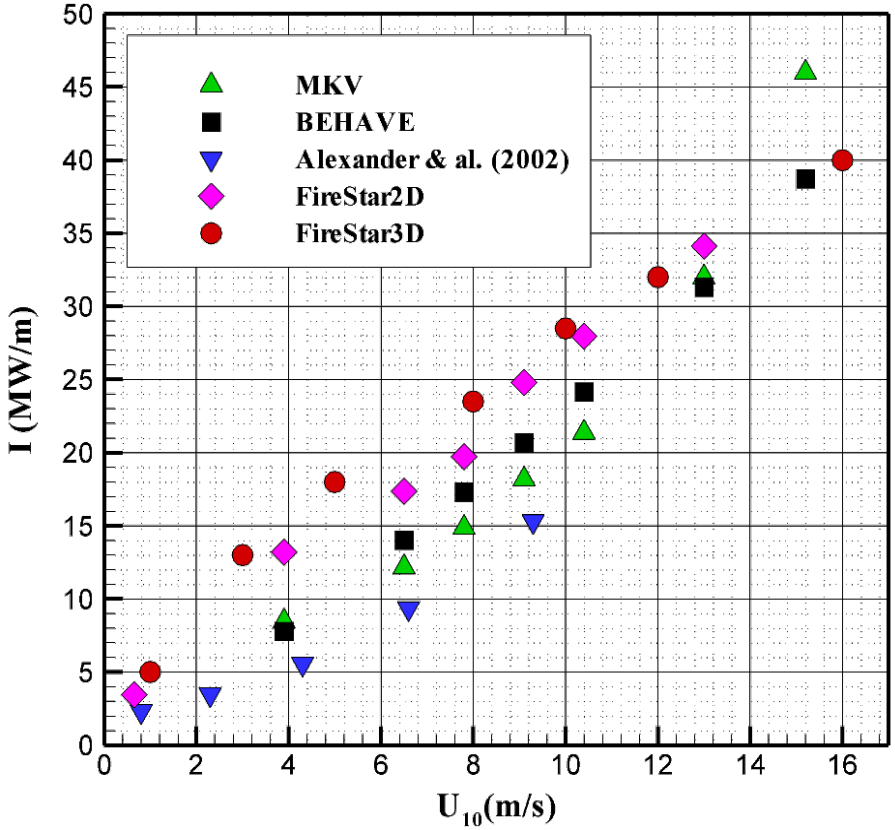


ROS and Fire Intensity ↔ Wind Speed

ROS

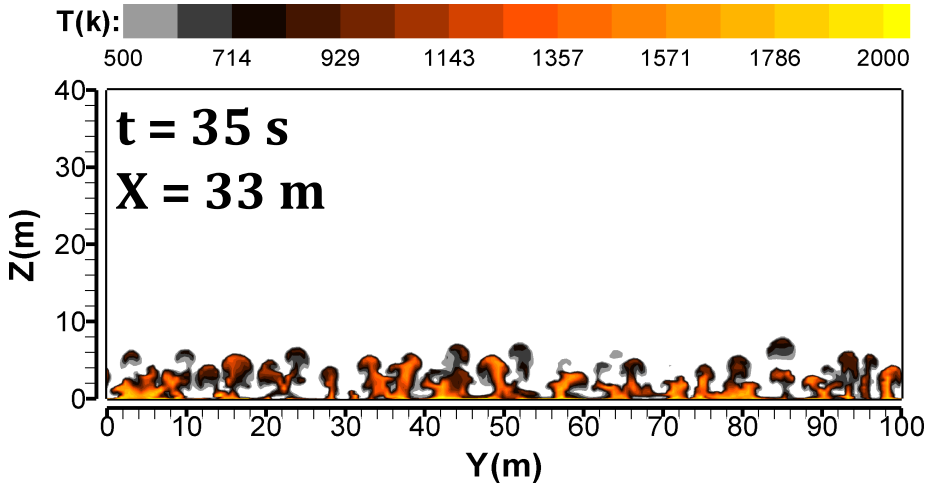


Fire Intensity

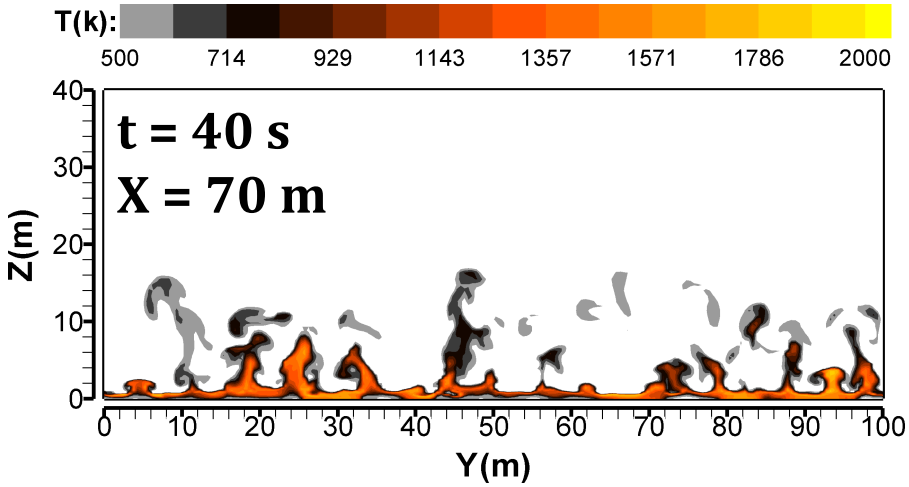


Flames Patterns ↔ Wind Speed

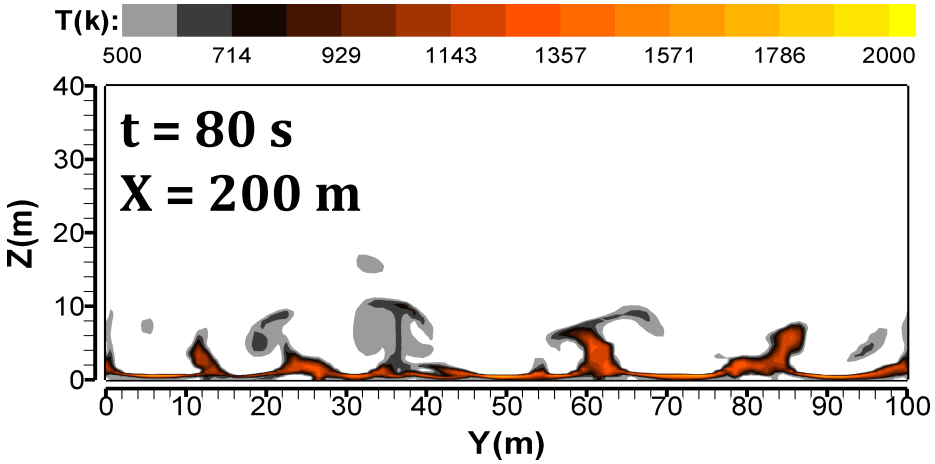
$U = 1$ m/s



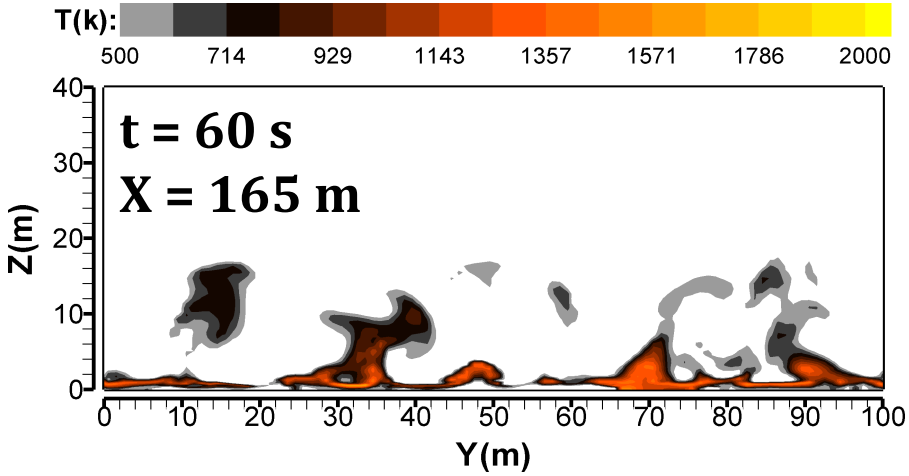
$U = 5$ m/s



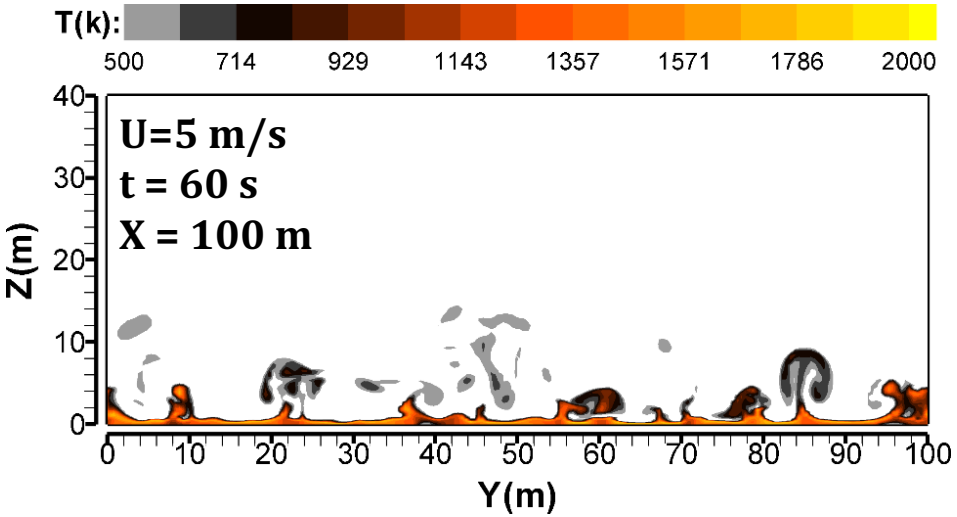
$U = 10$ m/s

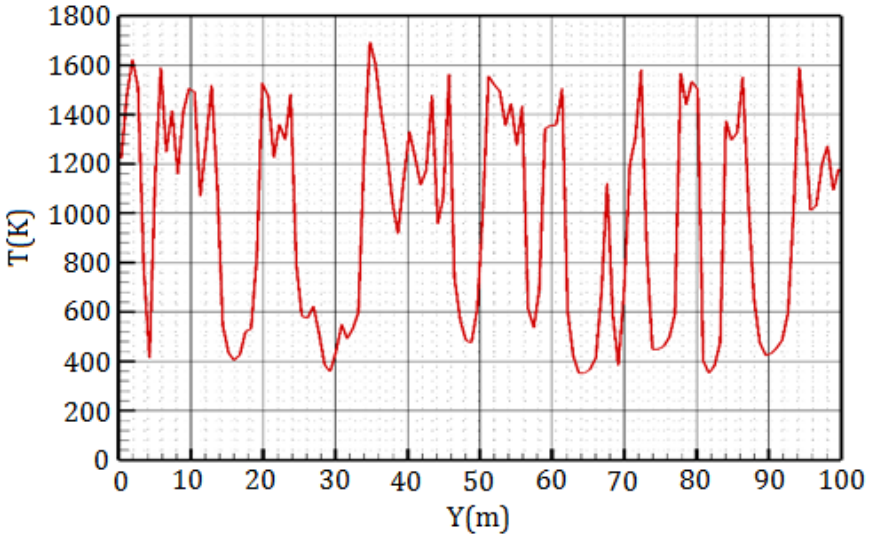


$U = 12$ m/s

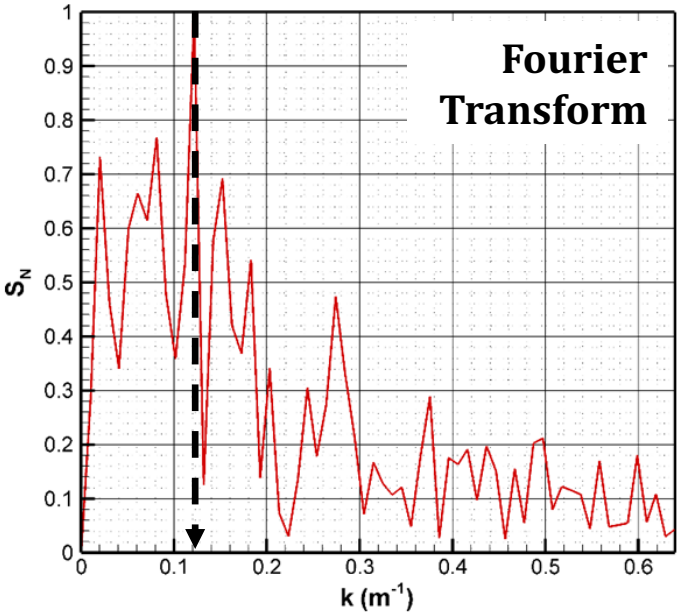


Fire front structure

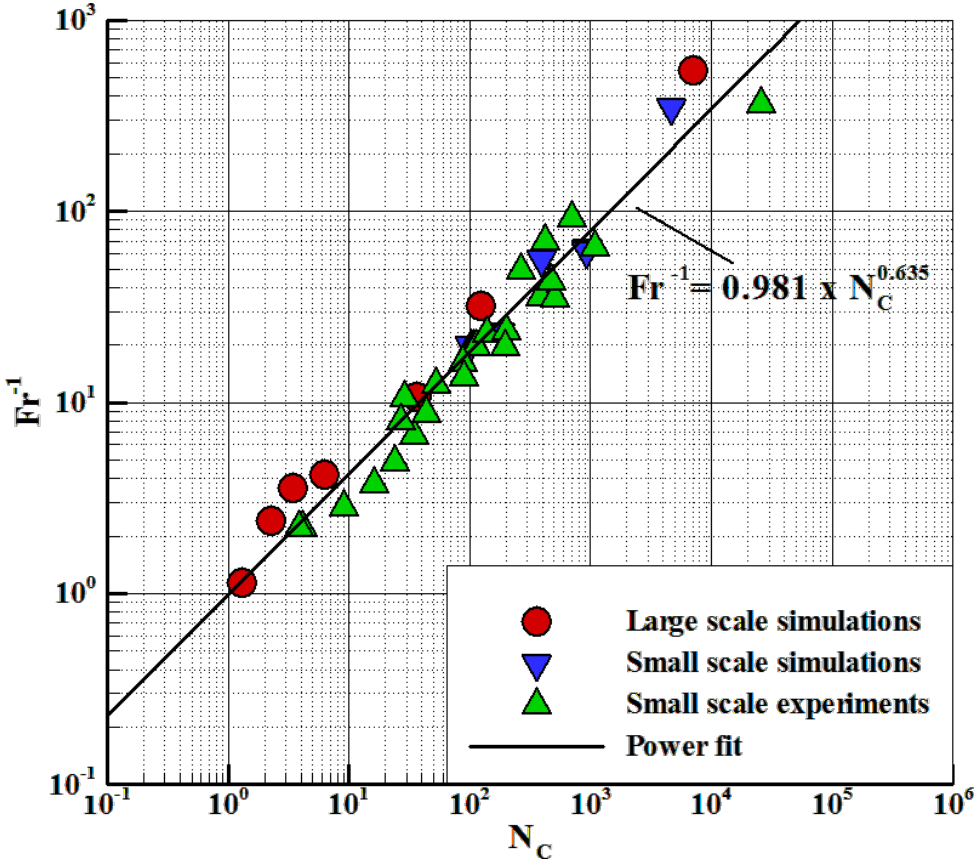




Wave number
$k = 0.11\ m^{-1}$



Similitude in fire-front dynamics



$$F_r = \frac{(U_{10} - ROS)^2}{g\,\lambda}$$

$$N_C = \frac{2\,g\,I}{\varrho_0\,C_{p0}\,T_0(U_{10}-ROS)^3}$$

$$\longrightarrow \quad \boldsymbol{Fr \approx N_C^{-2/3}} \longrightarrow \boldsymbol{\lambda \approx \left(\frac{2\,I}{\rho\,C_P T_0}\right)^{2/3} \frac{1}{g^{1/3}}}$$

FireStar3D Team

Gilbert Accary (Lebanon)

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Nicolas Frangieh (Marseille)


Thank You