GDR – RésoFeux, 2025

Experimental and Numerical Study on Flashovers Induced by VOC Accumulations in Forest Valley

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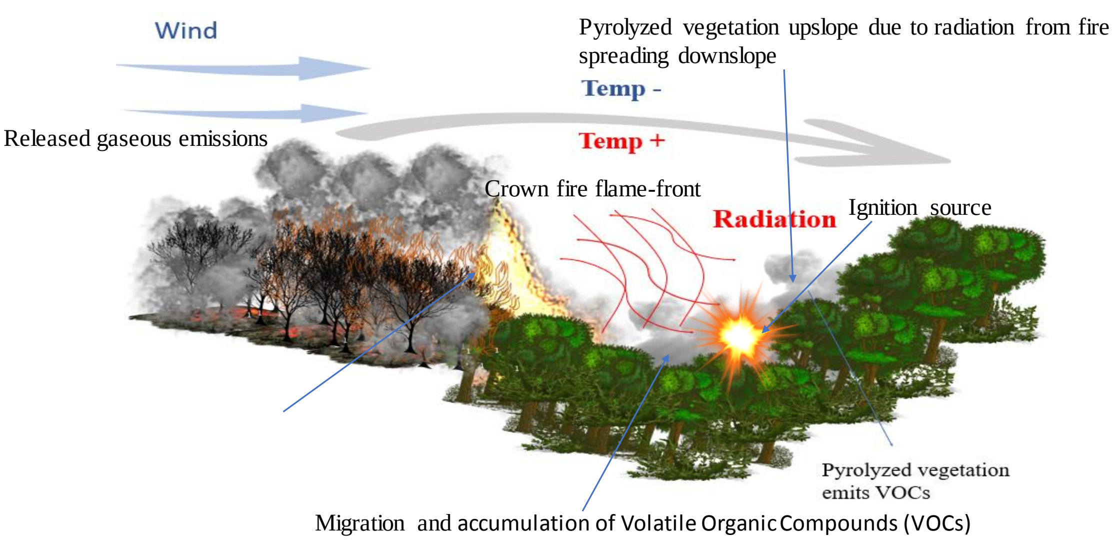
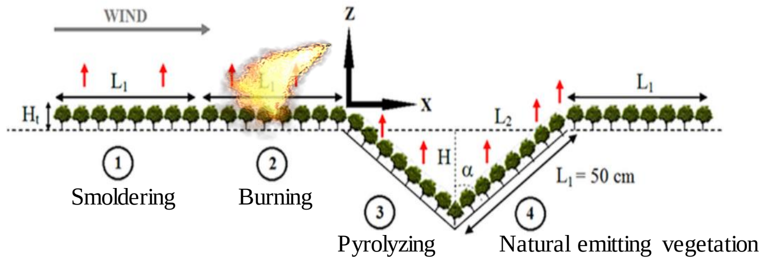
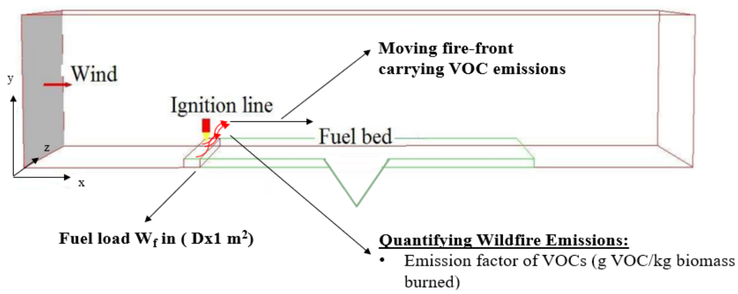
Flashover induced by VOC accumulations in a valley

(VOC concentration > Low Flammability Limit)



Forest model configuration with distribution of the trees





Numerical modelling

Mixture of gases

2D unsteady Euler-Euler approach (Star-CCM+)

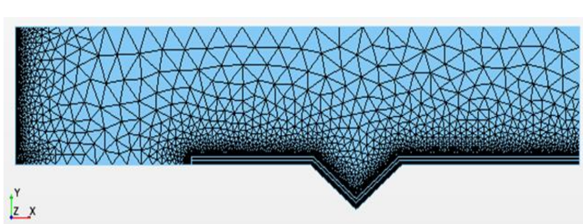
Conservation equations: mass, momentum, species, turbulence kinetic energy, turbulence dissipation

Porous Medium Model

Darcy's law : $-\nabla p = \frac{\mu}{Kp} Vs + b\rho|Vs|Vs$

Computational Mesh

Mesh cell of 3 mm near wall in log-law region, $30 < y^+ < 100$



Rothermel fire spread model

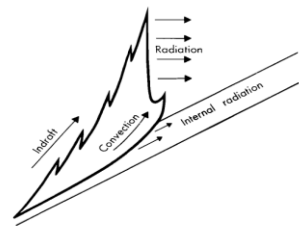
Surface fire spread rate : $\mathrm{ROS_{surface}} = \frac{\mathrm{I_p}}{\mathrm{Q^*_{ig}}}$

Propagation flux with wind and slope effects : $\mathrm{I_p} = \mathrm{I_R}\xi\,(1 + \phi_w + \phi_s)$

Reaction intensity : $\mathrm{I_R} = -\frac{dw}{dt} \times h$

Heat required to ignite a unit volume of fuel bed : $\mathrm{Q^*_{ig}} = \rho_b \mathrm{Q_{ig}}$

Flaming residence time :$\tau_R = \frac{384}{\bar{\bar{\sigma}}\,(\mathrm{inch}^{-1})}$

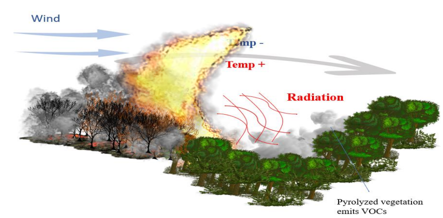


Transition of surface fire to a crown Fire (Van Wagner criteria**)**

$$ROS_{crown} = ROS_{surface} + CFB(ROS_{active} - ROS_{surface})$$

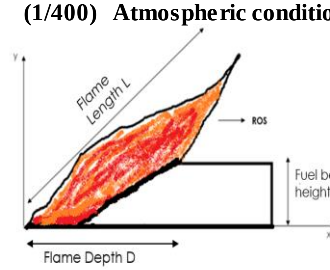
CFB (Crown Fraction Burned) = 1

Crown Base Height, Crown Bulk Density, Stand Height



Fuel bed characteristics, fuel load, moisture content, age, fire history

(1/400) Atmospheric conditions



Reaction intensity : $\mathrm{I_R} = -\frac{dw}{dt} \times h$ =3709.5 (Btu/ft^2.min)

Flaming residence time :$\tau_R = \frac{384}{\bar{\sigma}(\mathrm{inch}^{-1})}$ =2.6 (min)

Rate of crown fire spread : ROS_{crown} =1.6 (ft/min)

Fire line intensity :

$$I_{crown} = \frac{\left(HPA_{surface} + \left(W_{canopy}H_{canopy}CFB\right)\right)ROS_{crown}}{60}$$ =15579.9 (Btu/ft.min)

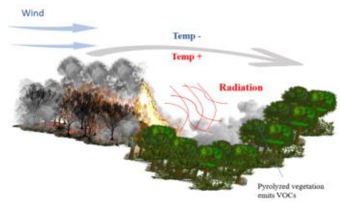
Flame length

$$L_{crown} = 0.45 \times (I_{crown})^{0.46}$$ =5.7 (ft)

Reaction zone depth

$$D_{crown} = \tau_R \times ROS_{crown}$$ =4.2 (ft)

Volatile Organic Compounds (VOCs) from longleaf pine forest fire



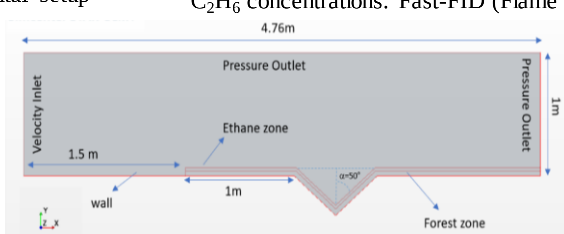
Most abundant compounds	**Emission Factors from prescribed wildfires** (g of VOC/kg of dry fuel burnt)	**Mass flow rate** (kg/s)
Methane	5.20	0.0552
Methanol	2.35	0.0249
Ethane	0.503	0.0053
Benzene	0.268	0.0028
Toluene	0.515	0.0055
α-pinene	5.05	0.0536

Validation of numerical model with ethane gas emissions

Experimental setup

Velocity measurements: LDV (Laser Doppler Velocimeter)

C_2H_6 concentrations: Fast-FID (Flame Ionization Detector)



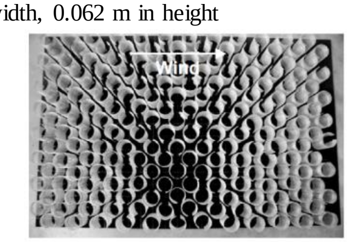
Forest dimensions in reduced-scale (1/400) : 2.5 m in length, 1 m in width, 0.062 m in height

Semi-angle: steep valley with α=50°, shallow valley with α=80°

Ethane injection in porous region : 1.9 g/m3/s

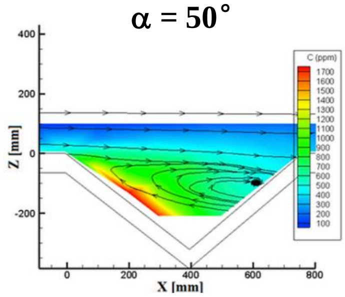
Porous region above a forest canopy: 400 metallic cylindrical tubes

Inlet velocity of crossflow : 6 m/s

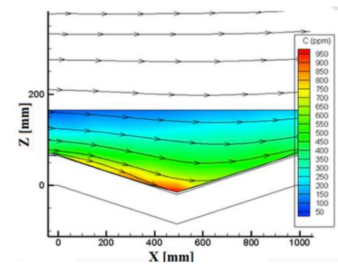


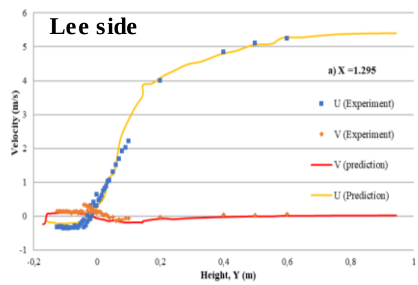
Horizontal (U) and vertical velocities (V)

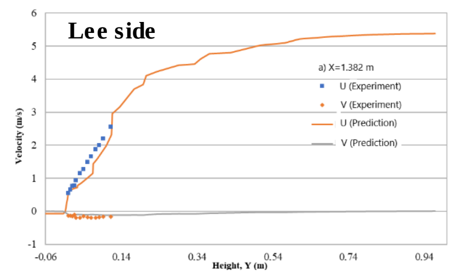
$\alpha = 50^\circ$



$\alpha = 80^\circ$

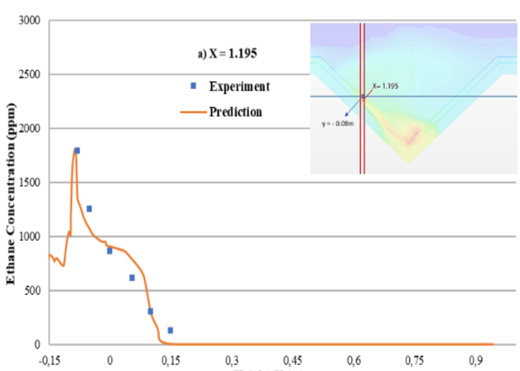




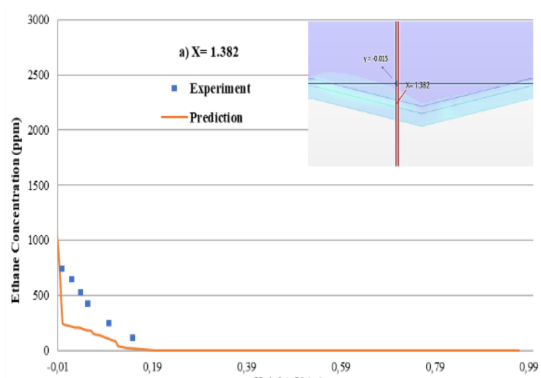


Concentration of C_2H_6 at the lee side

$\alpha=50^\circ$

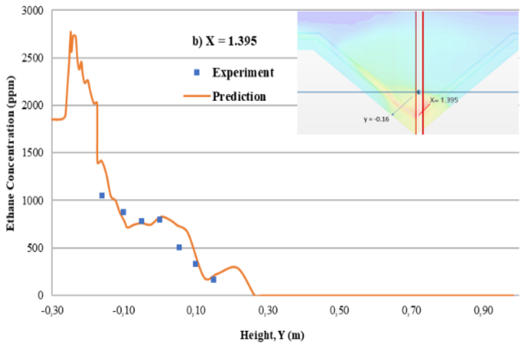


$\alpha=80^\circ$

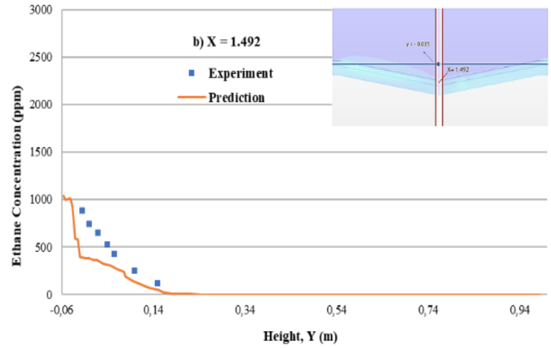


Concentration of C_2H_6 at the center

α=50°



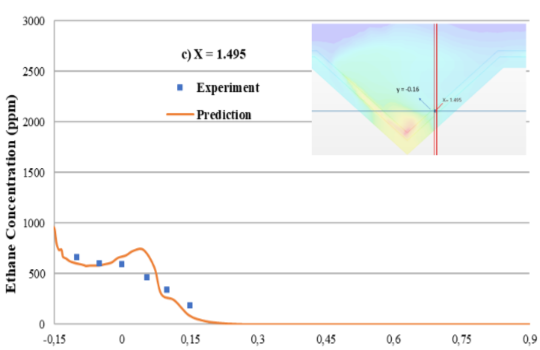
α=80°



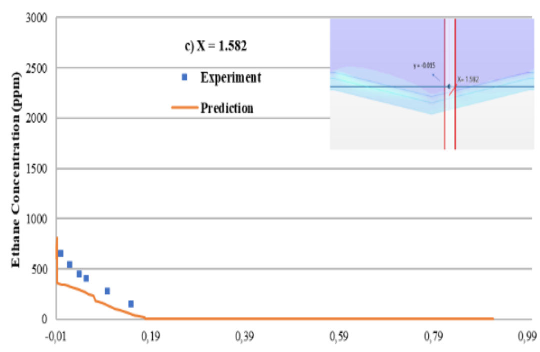
Insurmountable difficulty by using FID and LDV in the porous region

Concentration of C_2H_6 at the wind side

α=50°

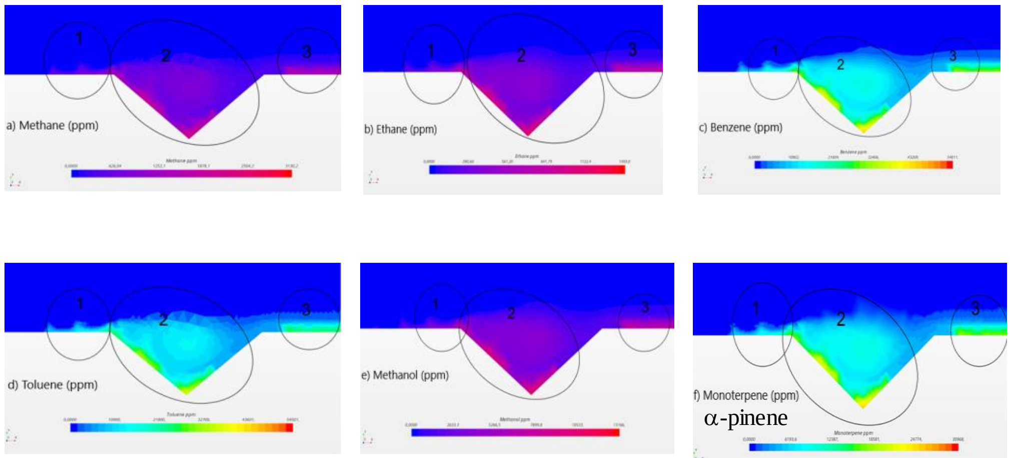


α=80°

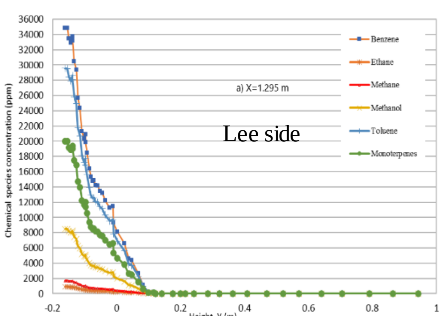


Most abundant compounds from wildfire at $\alpha = 50^\circ$ at valley edge

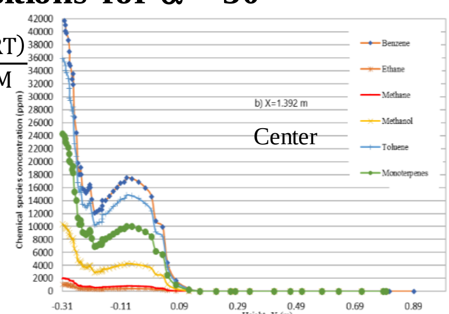
(α, ranging from 30° to 80° with a wind speed of 6 m/s)

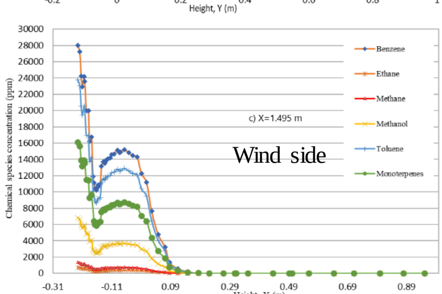


Concentration of the VOCs at three positions for $\alpha = 50^\circ$



$$\text{ppmv} = \text{mg/m}^3 \times \frac{(RT)}{M}$$





	LFL%	UFL%	Max ppm	%vol
Benzene	1.3	7.9	42355	4.2355
Toluene	1.2	7.1	35905	3.5905
α-pinene	0.8	6	24285	2.4285
Methane	4.4	16.4	2062	0.2062
Ethane	3	12.4	1100	0.11
Methanol	6	36	10325	1.0325

Conclusion and future investigation

- **Angle of a V-shaped valley which rangs from 30° to 80° influences significantly the dispersion of VOCs.**
- **Heavier compounds such as benzene, toluene and α-pinene reach the flammability limits with an angle below 60.**
- **Concentrations of the VOC compounds at the lee side and the centre of the valley are more critical than those at the wind side.**
- **Hotter smoke plume should bring a part of VOCs in the atmosphere via natural convection.**
- **Thermal effects influence behaviours of eruptive forest fires at a low wind speed.**