Comparative Study of Computational Electromagnetics Applied to Radiowave Propagation in Wildfires

Instituições Associadas

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Introduction

- Besides fauna and flora damages caused by wildfires, fires may also affect emergency communication systems;

- In 2017, the region of Pedrógão Grande in Portugal was affected by deadly wildfires and the Portuguese rescue communication network failed to assist forest fire victims.

- Since the 60's decade, fire fighters have testified the radio-wave propagation fragility all around the world;

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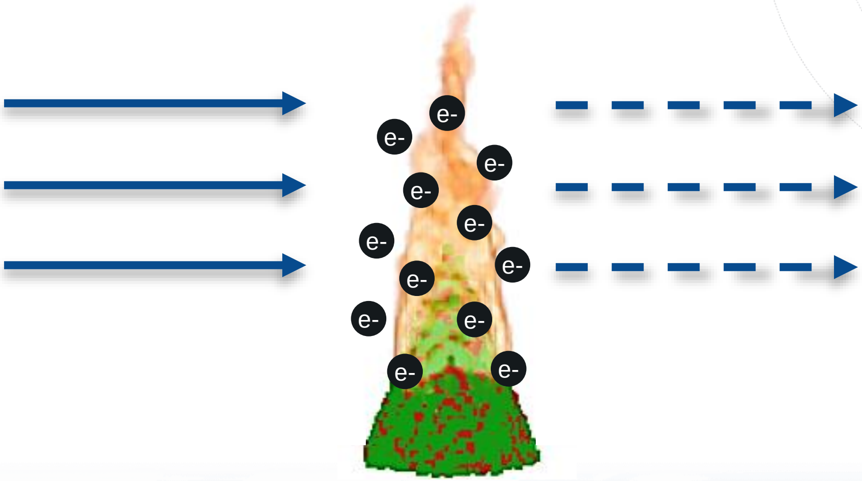
Modelling of radiowave propagation in fire

- One way to describe signal attenuation in wildfires is considering the Cold Plasma Model (CPM);



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Modelling of radiowave propagation in fire

- Estimation of electron density:

$$N_e = (K_1 N_a)^{\frac{1}{2}} \left[\left(1 + \frac{K_1}{4N_a} \right)^{\frac{1}{2}} - \left(\frac{K_1}{4N_a} \right)^{\frac{1}{2}} \right] [m^{-3}] \quad (1)$$

$$K_1 = 2 \frac{g_i}{g_0} \frac{2\pi mkT^{\frac{3}{2}}}{h^3} e^{-\frac{eV_i}{kT}} \quad (2)$$

$$N_a = n_0 + n_e = 7.335 \times 10^{27} \frac{\xi}{T} \; [m^{-3}] \quad (3)$$

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Modelling of radiowave propagation in fire

- Estimation of effective collision frequency:

$$\nu_{eff} = \frac{8}{3\sqrt{\pi}} N \left(\frac{m_e}{2kT_e}\right)^{\frac{5}{2}} \int_0^{\infty} \upsilon^5 Q^{(m)}(\upsilon) e^{-\left(\frac{m_e \upsilon^2}{2kT_e}\right)} d\upsilon \quad (4)$$

$$\Downarrow$$

$$\nu_{eff} = 7.33 \times 10^3 N_m a^2 \sqrt{T} \; [s^{-1}] \quad (5)$$

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Modelling of radiowave propagation in fire

- Relative permittivity:

$$\varepsilon_r = \left[1 + \frac{\omega_P^2}{\omega(i\nu_{eff} - \omega)}\right] \quad (6)$$

$$\omega_P^2 = \frac{N_e e^2}{m\varepsilon_0} \quad (7)$$

$$\omega = 2\pi f \quad (8)$$

- Propagation constant:

$$\gamma = \alpha + j\beta = j\omega\sqrt{\mu_0\varepsilon_0\varepsilon_r} \quad (9)$$

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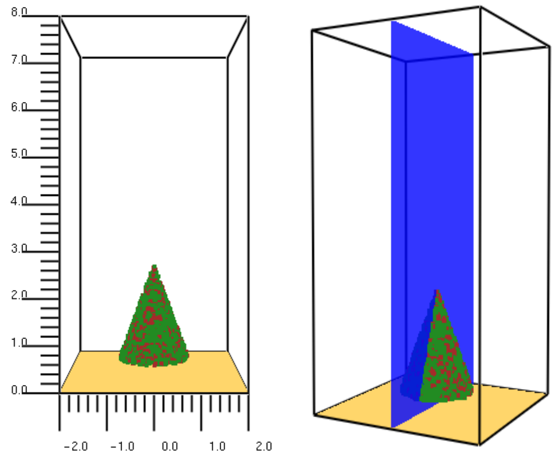
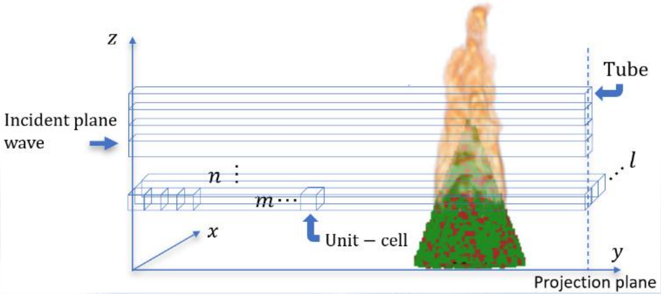
Modelling of radiowave propagation in fire

- Fire Dynamics Simulator (FDS) was used to model a fire scenario of a single tree over time.

- Parameters of a 30 s simulation:
  - *Eucalyptus Diversicolor* tree
  - K=0.9%, Ca=0.82% and Mg=0.28%
  - 385 MHz plane wave normally incident
  - Volumetric mesh of 5 cm cells
  - 80 slice divisions

FDS design





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Comparative study of computational electromagnetics

- Results obtained from CPM model are used as input parameters to 4 different approaches:
  - Full-Stack Model (FSM);
  - Transmission Line Model (TLM);
  - Finite-Difference Time-Domain (FDTD);
  - Commercial CST electromagnetic transient solver.

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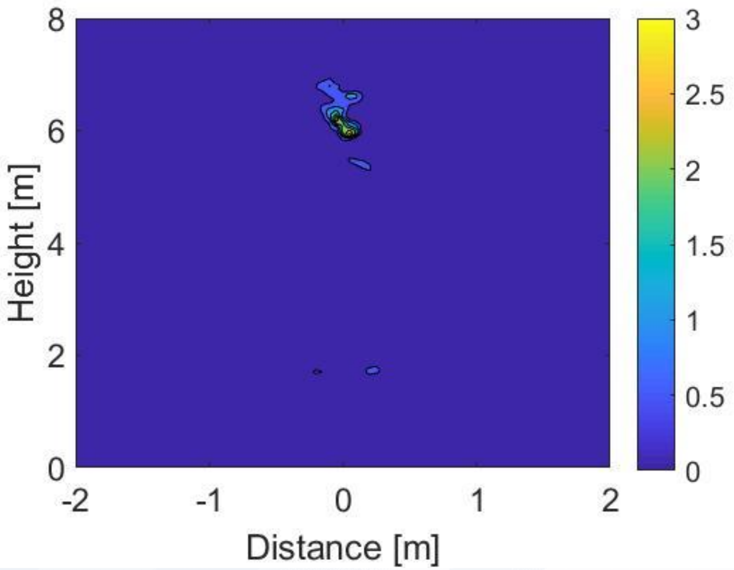
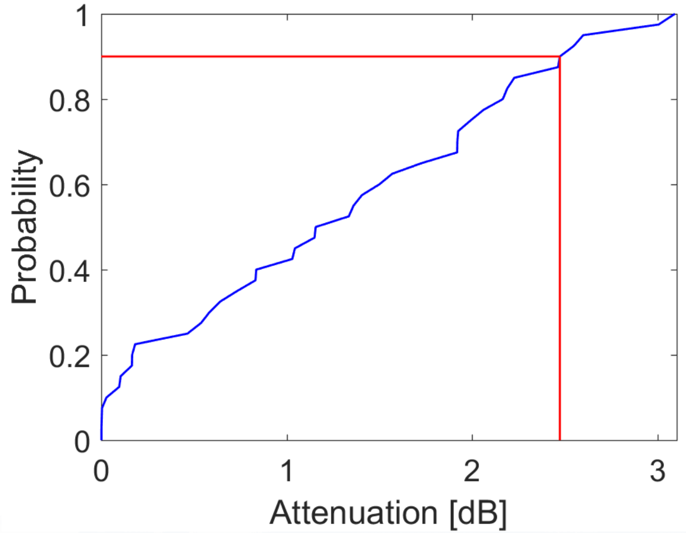
Comparative study of computational electromagnetics

- Full-Stack Model (FSM)





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Comparative study of computational electromagnetics

- Transmission Line Model (TLM)
  - TLM is based on impedance matching in multiple dielectric slabs, in which propagation and marching matrices are calculated, so that incident and reflected fields are considered at each unit-cell interface.
  - Total attenuation [in dB] on a per-tube analysis is in very good agreement with FSM.
  - The study of the CDF of the ROI was also performed, yielding a 2.42 dB of peak excess loss for 90% probability of occurrence, with a difference of only 0.05 dB to FSM.

- Full-wave analysis
  - Finite-Difference Time-Domain (FDTD)
  - Commercial CST electromagnetic transient solver

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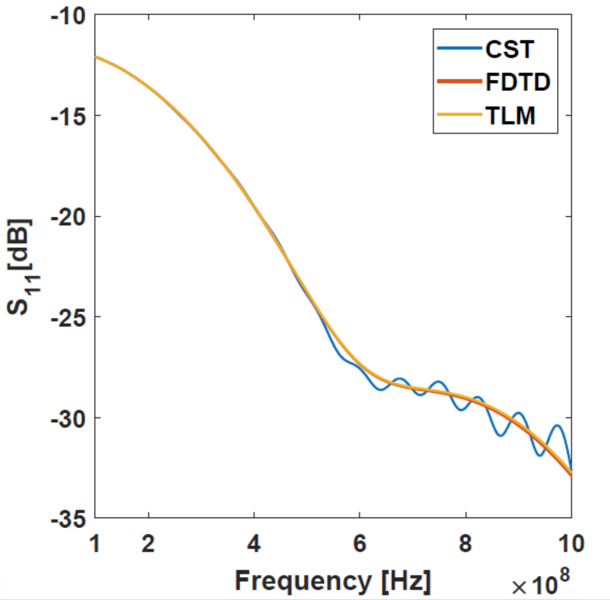
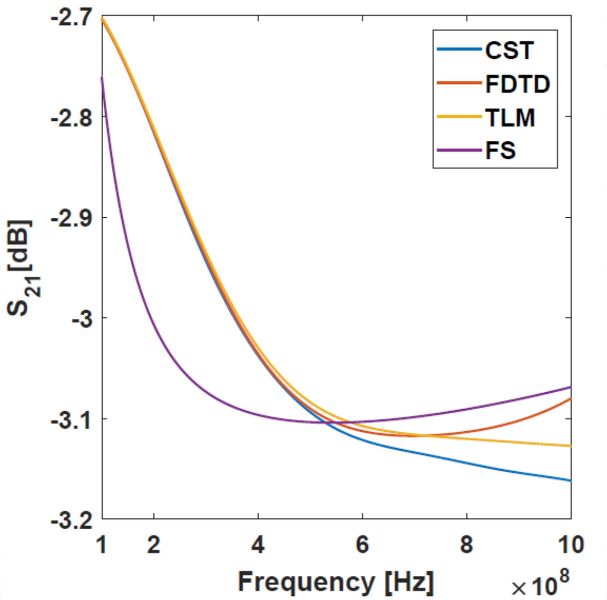
Comparative study of computational electromagnetics

- Comparative analysis





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Comparative study of computational electromagnetics

- Comparative analysis

	Number of tubes	Method			
		TLM	CST	FDTD	FS
S_{11} (dB)	1	-18.95	-18.91	-18.97	N/A
	4	-20.5	-20.65	-20.54	N/A
S_{21} (dB)	1	-3.019	-3.027	-3.024	-3.094
	4	-2.271	-2.295	-2.278	-2.337
	ROI (90% prob.)	-2.42	N/A	N/A	-2.47
Computational time (s)	1	<6	<30	600	0.005

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Conclusions

- This study clearly indicates that the effect of fire may dictate the reliability of the radio communications in critical mission applications;

- Signal attenuation in wildfires can be estimated by the cold plasma model (CPM), which was used to obtain the complex permittivity across the fire scenario;

- The complex permittivity allowed then to obtain the total attenuation of each tube on a projection plane, for four different methods.

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