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Modelling Pine Needle Surface Fires: A Comparative Analysis of up Slope Effects using a physics-based model

Surface fires are important in wildfire dynamics, burning vegetation near the ground and affecting fire growth. In certain situations, they can turn into crown fires, creating challenges for managing wildfires. This study investigates surface fires from pine needle fuel beds in a lab using Fire Dynamics Simulator (FDS) v6.8.0. Pine needle burning is worrisome in regions prone to wildfires and could result in transitioning to severe crown fires in pine plantations. Validation of FDS 6.8.0 is crucial for its use in wide range of complex scenarios due to its enhanced physics and chemistry compared to prior versions. This study conducted simulations on varying slopes (0°, 10°, and 20°) to explore how terrain inclination affects pine needle fire behavior. Comparison with Yang et al.[1]experimental results at 0° and 10° slopes revealed strong agreement. Additionally, we examined fire propagation under different slope angles (20°) to assess model accuracy across varied topographies.

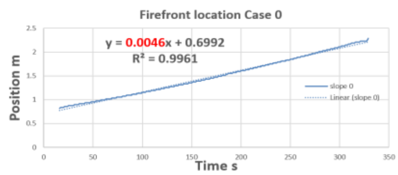
Methods

The present study validates a physics-based Computational Fluid Dynamics (CFD) wildfire model, focusing on surface fires. Its main aim is to improve understanding of surface fire spread across different slopes. In our study, we replicated the experimental setup [1]. The domain size was 6 m long (x = -2.25 to x = 3.75), 3 m wide (y = -1.5 to y = 1.5), and 2 m high. The boundary fuel model represented the vegetative fuel bed from x = 0 to x = 1.5 m and y = -0.5 to y = 0.5, consistent with the experiment. We maintained the fuel load at 1.2 kg/m² as in the experiment. Fig 1 shows the smoke view for each scenario. To simulate real-world conditions, we set the inlet, outlet, sides, and top boundaries as open, allowing for air inflow and outflow, consistent with the experiment. Furthermore, analysis of the data in Fig 2 shows that the fire front speed increases with an increase in the upslope angle, in line with findings reported in [2].

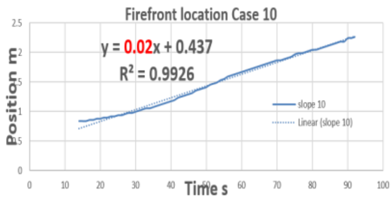
Results and Discussions

We determined the rate of fire spread (RoS) by extracting firefront locations, identified by a threshold surface temperature, along the central axis of the burnable pine plot at different time intervals from the boundary file using MATLAB. The RoS was quantified as the slope of firefront locations against time curve, providing insights into the dynamic fire spread behavior over time on varied slopes.

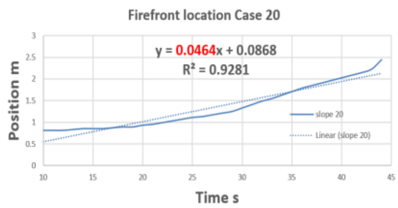
For case 0 , Fig 2 (a), (RoS) is 0.46 cm/s, close to Yang's study [1] which reported 0.507 cm/s. The relative error is 9.2%, indicating reasonable agreement between simulation and experiment. In Fig 2 (b), the simulation's RoS is 2 cm/s, notably higher than the experimental RoS of 0.7 cm/s for Case 10. This disparity indicates a lack of agreement between simulation and experimental outcomes for this case. In case 20 Fig 2 (c), the simulated RoS is 4.6 cm/s. However note that this specific case is not included in the experimental data. Using the step method instead of the gravity method in the simulation provides an alternative way to simulate the slope. We ran the simulation for up to 50 seconds, resulting in a Rate of Spread (RoS) of 0.53 cm/s, as depicted in Fig 2 (d), with a relative error of 0.25%.



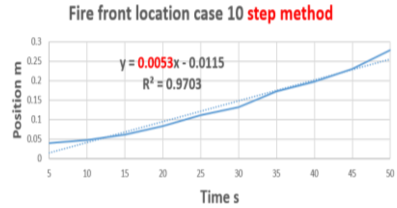
(a)



(b)



(c)



(d)

Fig 2. The fire front location vs time (a) case 0 (b) case 10 (c) case 20 (d) case 10 with step slope.

Conclusions

This study validates surface fire propagation on zero and upward slopes using FDS6.8. Key findings FDS6.8 simulation of zero-slope ROS has a 9.2% relative error compared to experimental data, and we are still working in slope 10 to get the lowest possible relative error.

References

[1] Z. Yang, H. Zhang, L. Zhang, and H. Chen, "Experimental Study on Downslope Fire Spread over a Pine Needle Fuel Bed," Fire Technology, vol. 54, no. 6, pp. 1487-1503, 2018, doi: 10.1007/s10694-018-0740-0.

[2]J. Cobian-Iñiguez, A. Aminfar, D. R. Weise, and M. Princevac, "On the use of semi-empirical flame models for spreading chaparral crown fire," Frontiers in Mechanical Engineering, vol. 5, p. 50, 2019.

Further information

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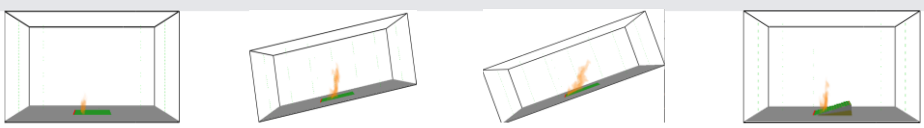

Fig 1. The smoke view (a) case 0 (b) case 10 (c) case 20 (d) case 10 with step slope.

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