IOCMA 2026 Conference

The 2nd International Online Conference on Mathematics and Applications

10–12 June 2026 | Online

MDPI

A Modified Level Set Framework for Physics and Uncertainty Informed Wildfire Spread

P.W.G.D.T. Wijeratna[1,*], S.H.D.S. De Silva[2]

[1,2]Department of Mathematics, University of Kelaniya, Kelaniya, 11300, Sri Lanka.

INTRODUCTION

Figure 01 - Wildfire Boundary Movement Detection

Wildfires are uncontrolled fires that spread rapidly through vegetation, causing serious environmental, infrastructural, and human impacts. Accurate modeling is crucial for effective risk management, preparedness, and resource allocation. However, many existing models rely on limited environmental variables and simplified assumptions, which restrict their accuracy in complex real-world conditions. This study proposes a modified Level Set framework that incorporates the Rothermel fire spread model along with environmental uncertainty to better represent realistic wildfire boundary evolution.

AIM & OBJECTIVES

Research Aim -

To develop a modified wildfire spread model by combining the Level Set Method, Rothermel fire spread physics, and uncertainty modeling for improved prediction of wildfire propagation

Research Objectives -

- **Model Integration** – Modify existing Level-Set models using Rothermel fire spread parameters for enhanced realism.
- **Dynamic Simulation** – Incorporate wind, fuel, and slope factors for dynamic fire boundary expansion.
- **Uncertainty** – Introduce randomness to represent environmental variability in spread behavior.
- **Verification** – Validate the modified framework using established elliptical wildfire spread behaviors.

METHOD

Initialization
Define initial fire front using elliptical and irregular ignition geometries in MATLAB.

↓

Physics Core
Compute local ROS using Rothermel parameters (fuel properties, wind, and slope).

↓

Stochasticity
Inject spatial variability to represent environmental uncertainty in the fire spread.

↓

Evolution
Iterative front propagation via numerical time stepping of the Level Set function.

MATHEMATICAL MODEL & PARAMETERS

Initial Fire Front (For Ellipse)

$$\phi(x,y,0) = \left(\frac{x}{a_0}\right)^2 + \left(\frac{y}{b_0}\right)^2 - 1$$

where:
a_0 – Initial major axis length
b_0 – Initial minor axis length
$\phi(x,y,0) = 0$ represents the initial fire

Level-Set Evolution Equation

$$\frac{\partial \phi}{\partial t} + v_n|\nabla\phi| = 0$$

with

$$v_n = R(\theta)\cos\theta_s + \Psi\xi_t$$

where:
v_n – speed in the normal direction of the fire front
$\Psi\xi_t$ – random disturbance term
$|\nabla\phi|$ – gradient magnitude of ϕ, defining front propagation speed
θ_s – slope influence angle

Parameter	Symbol	Value	Unit
Fuel Particle Surface-to-Volme Ratio	σ	5288.972	m^{-1}
Fuel Bulk Density	P_b	0.4055	kg/m^3
Fuel Load	W_0	2.24	kg/m^2
Fuel Bed Depth	δ	5.524	m
Packing Ratio	β	0.00316	dimensionless
Heat Content	h	18608	kJ/kg

Table 1: Simulation Input Parameters

RESULTS & DISCUSSION

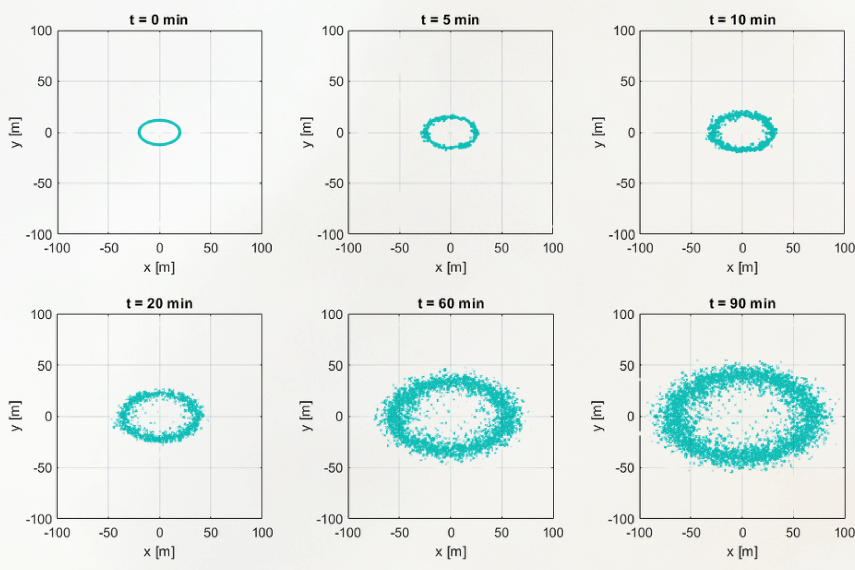

Figure 02 - Fire boundary development (new modified model)

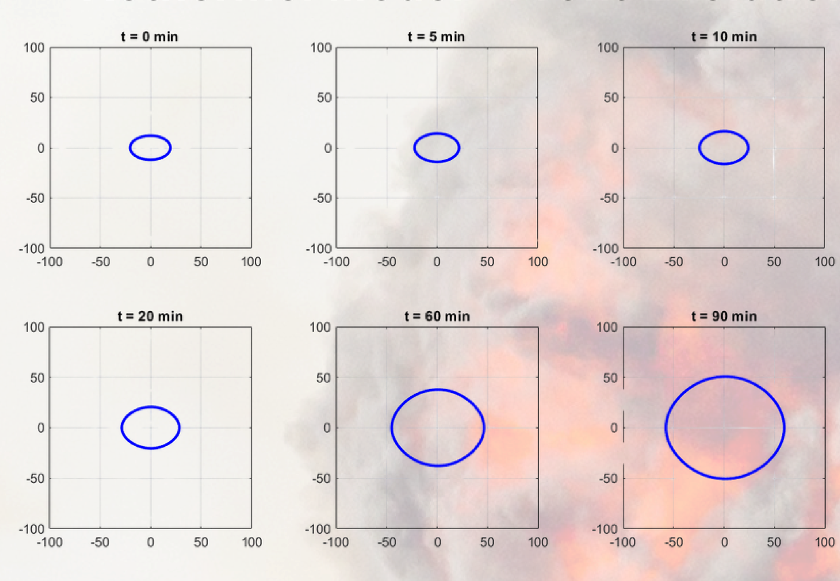

Figure 03 - Fire boundary development (standard Rothermel model)

Quantitative Comparison -

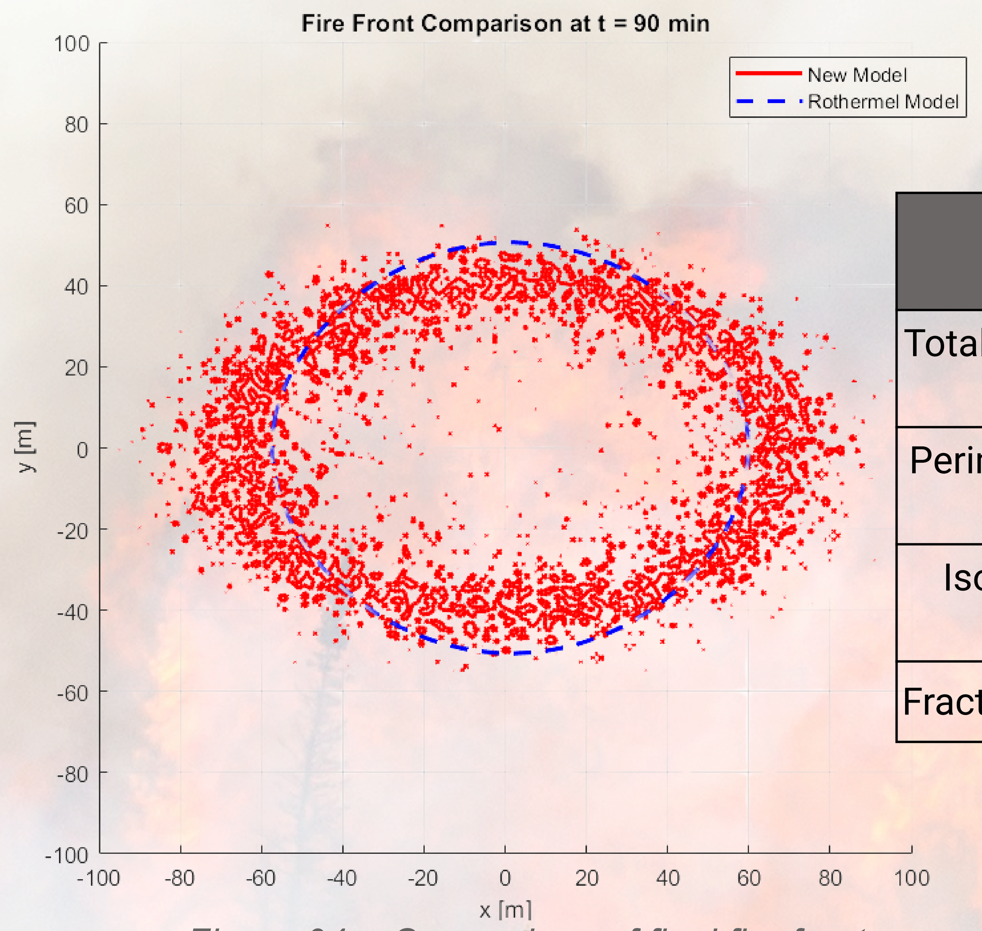

Figure 04 - Comparison of final fire fronts at t = 90 minutes

Metric	Standard Model	Hybrid Model	Difference (%)
Total Burned Area (m^2)	9,140.59	8,553.32	-6.42%
Perimeter Length (m)	348.12	382.45	+9.86%
Isoperimetric Quotient	0.94	0.87	-7.45%
Fractal Dimension	1.00	1.05	+5.00%

Table 2: Comparison of Elliptical Spread Metrics at t = 90 minutes

8,553.3
New Model Area (sqm)

9,140.6
Geometric Rothermel Area (sqm)

Area Ratio (New / Rothermel) : 0.94

The results demonstrate high agreement with standard geometric spread model while introducing realistic local variations

CONCLUSION

“This research successfully bridges physics-based modeling with geometric front tracking. The modified Level Set model correctly depicts the evolution of fire boundaries, achieving accurate spread predictions for elliptical scenarios while accounting for environmental uncertainty."

- Verified against basic elliptical spread behavior.
- Integrated Rothermel physics directly into Level Set evolution.
- Enhanced utility for predicting and controlling wildfire propagation.

FUTURE WORK

- Complex Shapes - Simulating ignition for complex random geometries and heterogeneous environments.
- Sensitivity Analysis - Detailed study of how specific fuel parameters impact boundary evolution under uncertainty.
- Real-World Validation - Comparing simulated perimeters with observed boundaries from global wildfire datasets.

REFERENCES

1. *“Pellizzaro G., Ghisu T., Arca B., Duce P. "A level-set algorithm for simulating wildfire spread". Computer Modeling in Engineering and Sciences (2014).*
2. *Yoo M., Wikle C. K. "A bayesian spatio-temporal level set dynamic model and application to fire front propagation". The Annals of Applied Statistics (2024).*
3. *Rothermel, R. C. "How to predict the spread and intensity of forest and range". Intermountain Forest and Range Experiment Station (1983).*
4. *https://share.google/I7r6V7Jpq5UxYFJGO (Figure 01)*
5. *https://share.google/AGwudMYOZJja6MHFe (Figure 01)*

https://sciforum.net/event/iocma2026