Hybrid Two-Dimensional Wildfire Growth Model for High Resolution Environments

Silvan Wiedmer[1,3][0009−0006−8760−8749], Stefano Balestra[2,3][0009−0002−5621−6655],
and Ralf-Peter Mundani[2,3][0000−0001−6248−714X]

[1] Swiss Institute for Information Science
[2] Institute for Data Analysis, Artificial Intelligence, Visualization and Simulation
[3] University of Applied Sciences of the Grisons, 7000 Chur, Switzerland

Abstract. This paper introduces a novel wildfire growth model designed for rapid, slope-driven wildfires in Switzerland. By combining raster- and vector-based approaches, the model leverages raster efficiency and vector prediction accuracy. As a result, the new model utilises high-resolution landscape data available in Switzerland, overcoming a key limitation of established wildfire simulation models. The proposed model builds on the raster-based Cell2Fire simulator, allowing direct comparison with the baseline in diverse landscapes. Comparisons against idealised reference fire perimeters show a significant F_1-Score improvement over the baseline, even with larger simulation time steps. These findings indicate that raster-based models can incorporate the proposed extension to improve predictions with minimal additional computational cost.

Keywords: Wildfire Simulation · Time of Arrival Computations · High Resolution Data.

1 Introduction

The first half of 2025 has already seen multiple record-breaking wildfires in both the United States and parts of Asia. The Los Angeles fires caused at least 27 deaths, and resulted in an economic loss of more than 250 billion USD [16]. Wildfires in South Korea and Japan burned approximately 7778 hectares of forest, likely caused by exceptional meteorological conditions influenced by climate change [6]. In addition to those current events, there is also a clear increase in wildfires when compared to historical records. Canada, for example, experienced a significant increase in wildfires during 2023, which was primarily due to record-breaking temperatures throughout the year [3]. This tendency also increases the risk of severe wildfires in central Europe, which was traditionally considered a low-risk region for wildfires, demonstrating the need for fire management [13]. Switzerland too is experiencing a growing risk of wildfires, particularly in the Locarnese region (Canton Ticino, Switzerland) [1]. This increase in wildfire risk, caused by climate change, is expected to increase the frequency of extreme fire events [4].

ICCS Camera Ready Version 2026
To cite this paper please use the final published version:
DOI: 10.1007/978-3-032-29924-6_1

To minimize the potential damage caused by wildfires, reliable and operational wildfire simulations are essential for fire management actions and suppression strategies [21]. These simulations enable authorities to respond effectively by implementing preventive measures and deploying efficient real-time countermeasures to protect cities, wildlife, and suppress wildfires.

Since the behaviour of wildfires is largely dependent on the environment, wildfire simulation software, such as FARSITE [9] in the United States and Prometheus [20] in Canada, are highly specialized and parametrized towards their respective regions. This work investigates the advantages of wildfire simulation approaches based on high resolution data (as available in Switzerland, e.g.) and proposes a new simulation model to address specific regional requirements that are not met by existing well-established models.

Given the country's distinct environmental conditions and the availability of high-resolution datasets (cell resolutions of $0.5\,\mathrm{m} \times 0.5\,\mathrm{m}$), there is a clear need for a highly optimised model that maintains state-of-the-art accuracy. Although the model is designed with future parallelisation in mind to conform to the computational requirements, it is not yet parallelised. The results of this work have both theoretical and practical significance as the developed model provides a foundation for future wildfire simulations in Switzerland and contributes to ongoing research on hybrid modelling approaches.

The remainder of this paper reviews related work, describes the proposed model, presents the results, and concludes with a discussion.

2 Related Work

Various approaches exist for wildfire simulations. The extensive review by [17–19] showed that simulations intended for operational use are primarily done using specialized simulation models. Such models have existed for many years and have been applied in various environments. FARSITE, for example has been specifically designed for the United States and is generally regarded the state of the art in terms of fire perimeter accuracy [10]. The two common modelling strategies are raster- and vector-based approaches. Raster models are typically much faster than vector models, but are lacking in the accuracy domain. Therefore, newer models like Cell2Fire [14] and Pyros [21] try to combine these approaches to get a best-of-both-worlds approach, which offers comparable accuracy to vector models with much improved simulation efficiency.

When it comes to wildfire simulations, there is a clear distinction between wildfire behaviour and wildfire growth modelling, with the latter being the focus of this work. It has to be noted that wildfire propagation is sometimes used as a synonym for fire growth in the literature, whereas fire spread may substitute fire behaviour. Fire behaviour refers to models that calculate the Rate of Spread (ROS) as well as the fire intensity, based on homogeneous landscape and weather conditions. The ROS defines how fast the fire front moves in a particular direction and has the unit [m/min] [2, 9]. Specifically, these metrics are calculated mainly based on both fuel type and moisture, wind velocity, and slope [14]. Fire growth

ICCS Camera Ready Version 2026
To cite this paper please use the final published version:
DOI: 10.1007/978-3-032-29924-6_1

models, on the other hand, use the homogeneous fire behaviour predictions and grow the fire perimeter over heterogeneous landscapes including terrain, fuel and weather changes [11]. These models commonly rely on the assumption that the fire front of two-dimensional fires can be represented as an ellipse when all factors affecting fire behaviour are spatially and temporally constant (homogeneous) [9].

The complex three-dimensional process of wildfires is represented by the use of multiple fire behaviour models [9]. These models independently describe surface fire, crown fire, spotting, and rate of spread acceleration. Surface fires burn up fuels in contact with the ground like grass, shrubs, or downed wooden fuels, while crown fires describe the combustion of tree canopies. Another important phenomenon is spotting, which can rapidly advance wildfires by igniting new fires well ahead of the current fire perimeter. It is caused by firebrands transported by the wind, travelling many kilometres and even crossing firebreaks. Lastly, fire acceleration describes the rate at which the ROS of the fire front can adjust to new environmental conditions.

Evaluating wildfire simulations remains challenging as the use of an experimentally validated Rate of Spread (ROS) model does not inherently ensure the validity of the resulting fire perimeter [5]. To address this, many authors, such as [15, 21], tend to incorporate idealised and historical fires for model evaluation. The simulation result is often represented as a binary raster grid, allowing cell-wise comparison with reference data in a confusion matrix framework [14, 21]. In the context of operational wildfire management, type II errors are considered more critical than type I errors, as they represent burned areas that were not predicted as such [21].

The overview of key wildfire growth models highlights two important aspects. First, the well-established vector models, FARSITE and Prometheus, remain widely used due to their state-of-the-art accuracy [10]. Second, newer models such as Cell2Fire and Pyros tend to use raster-based or hybrid approaches to achieve significantly faster computational times while maintaining fire perimeter accuracy comparable to FARSITE and Prometheus. Here, it is important to note that the use of local elliptical spread, as used by Cell2Fire, does not make the model a hybrid approach, as the model propagates the fire using local neighbourhood rules and exports the final fire perimeter in raster format.

The current literature suggests that raster-based and hybrid models are the most viable options to meet the computational demands required by faster than real-time simulation in high resolution environments. These models demonstrate significant performance improvements over the traditional vector models FARSITE and Prometheus while maintaining comparable accuracy. Notably, both Pyros and Cell2Fire simulate fire spread using elliptical shapes but represent the final fire perimeter using raster cells. In Pyros, each fire agent expands its ellipse across multiple cells, which assumes uniform environmental conditions during a single time step. To satisfy this assumption in heterogeneous environments, the time step must be reduced so that the fire spread only occurs in homogeneous conditions. This constrains the spread to local neighbourhoods, similar to Cell2Fire, and therefore reduces the benefits of the hybrid approach

ICCS Camera Ready Version 2026
To cite this paper please use the final published version:
DOI: 10.1007/978-3-032-29924-6_1

implemented in Pyros, particularly in high-resolution, heterogeneous environments.

3 Implementation

The simulation model developed in this work excludes fire behaviour models other than surface fires, suppression activities, and the incorporation of weather data. As Pyros already uses a hybrid approach determined to be non-optimal for high resolution environments, the Cell2Fire model serves as basis for model development. This allows for a direct assessment of the computational overhead created by the new model as well as possible accuracy improvements.

3.1 Reference Simulation Model

The baseline model uses an elliptical spread which is calculated in each timestep based on the fire behaviour and the time since cell ignition. When this ellipse reaches the centre of a cell in its Moore neighbourhood it ignites it (see Fig. 1). To ignite a cell, its state is changed from *Available* to *Burning*. Next to that there are also states for *Burned*, *Treated*, and *NonFuel*.

To verify the re-implementation of the model, we performed a plausibility check against idealized fire scenarios. Our results demonstrated a high degree of convergence with other raster-based simulators found in the literature across both flat and sloped terrain [15].

3.2 Model Development

Both Cell2Fire and Pyros propagate the fire front using some form of vector approach, but they still represent the final perimeter in the raster format. Depending on the size of a cell, there is the potential to incorrectly classify a relatively large area especially when using cells of $25\,\text{m} \times 25\,\text{m}$, which is generally used by operational models [9, 20, 21]. Therefore, the idea of the new hybrid approach is to extract the vector-based fire front from the local spread ellipses when exporting the fire perimeter. This is done at the end of the simulation or at user-specified export intervals (for visualisation of intermediate time steps) and does not change the propagation logic.

While this extension helps to improve the accuracy of the fire perimeter, it does not entail large computational overhead. As the spread is still based on the local ellipse as used in Cell2Fire, there is no need for the expensive crossover removal used in vector models like FARSITE, thus avoiding one of the main weaknesses of the vector based approach [9, 15].

Vector Front Extraction (V1) The idea for the first version of the model (V1) is to store the directional spread distance for each burning cell during simulation. Since this value must be computed for each burning cell in every iteration, the

ICCS Camera Ready Version 2026
To cite this paper please use the final published version:
DOI: 10.1007/978-3-032-29924-6_1

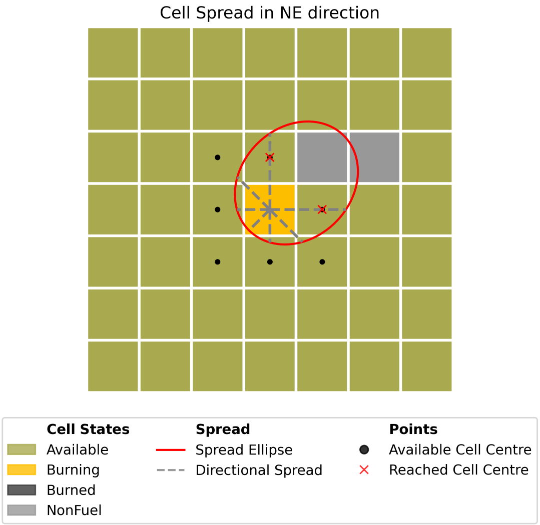


Fig. 1: Local Cell-to-Cell propagation in the north-east (45°) direction, as proposed by [14]. Each burning cell expands a local fire spread ellipse and checks if the cell centres of the *Available* cells in its Moore neighbourhood are within this ellipse. If so, the cell gets ignited in the next time step.

already calculated spread distances are stored in a one-dimensional vector for each cell. Since the fire can spread from a single cell to every cell in its Moore neighbourhood, the vector has eight entries.

To get the fire perimeter, the simulation must first find the edge of the fire front. This is done by looping over all the available cells in the simulation grid and checking if the cell has at least one neighbouring cell which has the state *Burning*. By looping over all edge cells, the previously stored directional spread distances can be extracted from cells that are *Burning*. The extracted point can then be used to create the vector fire perimeter.

Exact Time of Arrival Calculation (V2) During the development of Version 1, the possibility of a further improvement was found which uses the stored spread distances to optimise the local propagation rules. In V1, the fire spread ellipse of a cell is determined by calculating the cells ROS and multiplying it by the time the cell has been burning for. This burning time is calculated by subtracting the ignition time from the current simulation time. The issue with this approach is that the ignition time is set to the next time step, even when the actual ignition is closer to the previous iteration. This results in the fire spread ellipse of the newly ignited cell being too small in every case except an exact match between the directional spread and the cell distance. The idea of this optimisation is that the model can achieve the same accuracy as before while using much larger time steps, potentially reducing execution time.

ICCS Camera Ready Version 2026
To cite this paper please use the final published version:
DOI: 10.1007/978-3-032-29924-6_1

As both the distance to each cell and the directional spread are calculated to check whether the fire has reached a cell centre, it can also be used to calculate the exact time of arrival of the fire in the cell centre and use this time as the actual ignition time of the first ignition. Using the directional spread distance and dividing it by the time step size returns the ROS for the spread along this axis. The ignition time t_{ign} is then calculated using the following equation

$$t_{ign} = t + \frac{d}{ROS} \tag{1}$$

where t represents the ignition time of the cell that is currently burning, d the distance between the cells, and ROS the directional spread rate calculated beforehand.

Vector Fire Perimeter The raster-based perimeter points must be converted into a vector fire perimeter. A simple approach is to use the convex hull of the spread-direction points from the edge cells. This is however only valid for idealised cases with a single fire in a uniform, unobstructed landscape. Real fire perimeters are often concave due to obstacles and may contain non burnable islands (see Fig. 2b).

To solve this, a new approach is developed relying on a sub-cell-level raster implementation. The idea is that each edge cell creates a convex hull within itself, using the directional spread points from its neighbours as well as the cell boundary points (see Fig. 2a). Then, the newly generated geometries are rasterized at sub-cell resolution, setting the state of all touched sub-cells to *Burning*. The vector perimeter can now be exported from the sub-cell resolution grid using the contours of the features (cells that are either *Burning* or *Burned* are *ones* and everything else *zeros*) in the landscape (see Fig. 2b).

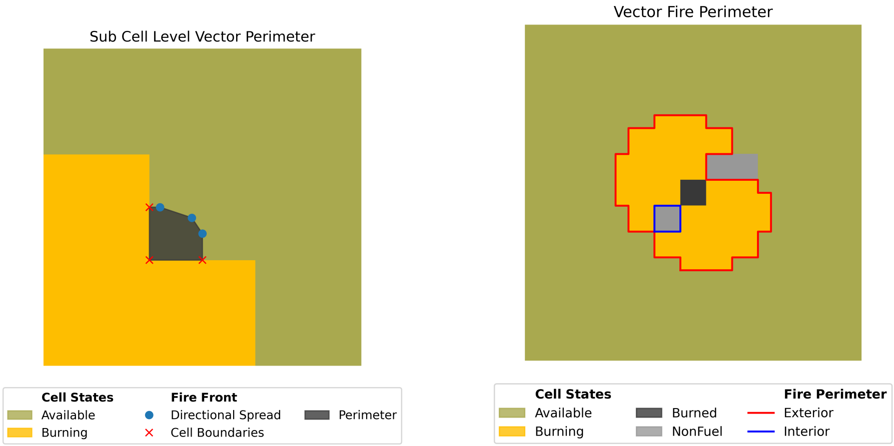
4 Results

In the following, we present first results obtained with our new simulation model. The simulations were conducted on a 2023 M3 Pro Mac Book Pro with 36 Gb of Unified Memory. Since type II errors are critical for operational fire management [21], recall is used for type II error assessment, precision for type I errors, and the F_1-Score to quantify the overall similarity between two fire perimeters.

4.1 Idealised Fires

For evaluation, both the baseline and developed models are first compared to idealised fire scenarios including circular fire spread and slope driven spread. These scenarios, using homogeneous wildfire spread ellipses, are defined on a 100×100 cells simulation grid with a cell size of 30 × 30 meters. To ensure the gains from the vector-based perimeter are measurable, the evaluation grid is set to a resolution of 200×200 cells, which splits the original cells into four new

ICCS Camera Ready Version 2026
To cite this paper please use the final published version:
DOI: 10.1007/978-3-032-29924-6_1



(a) Cell based vector fire front.

(b) Vector Representation of raster based fire front.

Fig. 2: Vector fire perimeter calculation using the sub-cell level raster implementation. Each cell calculates a local convex hull around its interior spread points (a) and rasterises the result on a sub-cell level grid. The resulting fire perimeter (b) is represented both in raster format and can be exported as a vector using the contours of the raster perimeter.

cells. The F_1-Score, precision, and recall scores for the three models are listed in Table 1.

The results show that V2 achieves substantially higher recall than both the baseline and V1, while precision remains comparable across models. This suggests a slight over-prediction of the fire perimeter, but an overall improvement, as the new model misses fewer actively burning cells and misclassifies fewer non-burning cells. Overall, V2 outperforms the original Cell2Fire implementation in both scenarios. The F_1-Score differs markedly between simulations with and without slope, and while incorporating the vector perimeter in V1 yields minor gains over the baseline, the main performance improvements come from the exact time-of-arrival calculation.

4.2 Parameter Studies

The results on idealised fire scenarios show a small part of the model performance. To assess how time step size affects prediction accuracy and how perimeter export frequency impacts execution time a parameter study is included.

Time Step Size Similar to the Courant–Friedrichs–Lewy (CFL) condition in computational fluid dynamics, a restriction is placed on the time step size such

ICCS Camera Ready Version 2026
To cite this paper please use the final published version:
DOI: 10.1007/978-3-032-29924-6_1

Table 1: Evaluation scores for the different models on idealised fire scenarios (with and without slope). The simulation time was set to 50 min, with a time step size Δt of 60 s and a ROS value of 10 m/min.

Model	Idealized Fire	F1 Score	Precision Score	Recall Score
Cell2Fire	No Slope	0.8725	0.9950	0.7769
Version 1	No Slope	0.8752	0.9985	0.7790
Version 2	No Slope	**0.9486**	**0.9987**	**0.9032**
Cell2Fire	Slope	0.7493	**0.9989**	0.5995
Version 1	Slope	0.7493	**0.9989**	0.5995
Version 2	Slope	**0.9025**	0.9893	**0.8298**

that the simulation does not advance further than its adjacent cells per time step. Although the time step size of 60 s does not break this restriction enforced by Cell2Fire, it could still be considered coarse, as there are only three time steps required to reach the centre of a cell in the Neumann neighbourhood when assuming circular spread. Figure 3 presents the time step parameter study for both slope and no-slope scenarios.

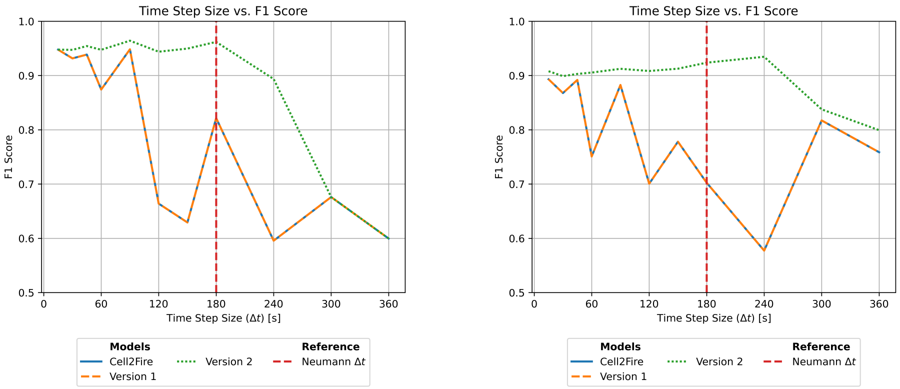
As the extension of the baseline model is designed for large time steps, it is to be expected that all three models perform similar when using a small time step size regardless of the scenario. Taking a closer look at the fire perimeters simulated by the parameter study reveals some interesting insights.

All models fail to create a circular shape on flat terrain when the time step size is 240 s or greater. The Cell2Fire reference implementation and V1 are however much worse at predicting both the shape and size of the circle than V2. This is due to the time of arrival approach correcting for the error caused by the coarse time step. When using small time steps on sloped terrain, all model predictions are similar in size and shape, while the additional vector-front of the newer models seems to over-predict the backing fire. This problem of the vector-front remains for all the tested time steps, which is in agreement with the slightly lower precision scores shown in Table 1.

The results show that V2 is much better at predicting a perimeter shape close to the expected shape. All models suffer from the perimeter distortions due to limited spread directions which is known to be a significant challenge for raster-based models [21]. Finally, the new model can achieve accuracy comparable to the base model while using larger time steps, which can drastically improve the computational time required. The results further support the findings from the scores in Table 1 that the use of only the vector front does not drastically improve accuracy.

Execution Time The impact of the new model adaptation in regard to execution time was also assessed. As the vector-based fire perimeter must be calculated from the current state of the raster-based spread, it is expected to impact per-

ICCS Camera Ready Version 2026
To cite this paper please use the final published version:
DOI: 10.1007/978-3-032-29924-6_1



(a) No Slope (b) Slope

Fig. 3: Time step size parameter study on idealised fires without slope (a) and with slope (b), using time step sizes ranging from 15 to 360 seconds. The study used a fixed ROS value of 10 m/min and a constant grid resolution of 30 m. The red vertical line indicates the time step at which the fire reaches the centre of the Neumann Neighbourhood cells within a single time step when using circular spread.

formance based on the number of exports to be made. It should be noted that the model is not extensively optimised for sequential execution speed.

The study was conducted by running multiple simulations per model and altering the time between each export. The run-time of the baseline model remains relatively constant, showing only a slight increase in simulation time. This result is expected, as the model can simply store the simulation grid without any further processing. Both versions, V1 and V2 can have a negative performance impact in comparison to the baseline model but this solemnly depends on the user-defined export interval.

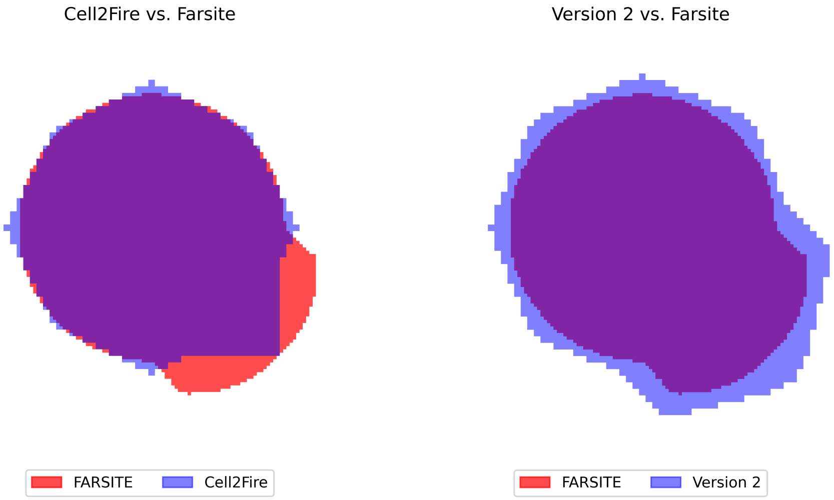
4.3 Reference Model

To evaluate the model under heterogeneous conditions, it is tested against FARSITE using a simplified scenario. To do so a new idealised wildfire scenario is created with no slope, where a small area of fuel is set to a different type from the rest resulting in a concave shape. Other influence factors such as wind and point source fire acceleration are turned off in FARSITE for this comparison. It should be noted that FARSITE was used as part of the FlamMap software package [12] for this evaluation.

Even after turning off these relevant features, such as wind, and point source fire acceleration, the simulation using the same value for simulation time (t) resulted in a fire perimeter much bigger than the perimeter predicted by FARSITE.

This suggests that the previous adjustments made to ensure comparability are insufficient for an exact match between the models. Therefore the simulation time was set to a value that approximately matches the size of the reference shape and the results are only assessed visually.

The inspection of the resulting perimeters (Fig. 4) show the perimeter distortions of both models when compared to FARSITE. However, V2 is much closer in the general shape of the fire than the Cell2Fire implementation.



(a) Cell2Fire fire perimeter comparison against FARSITE

(b) V2 fire perimeter comparison against FARSITE

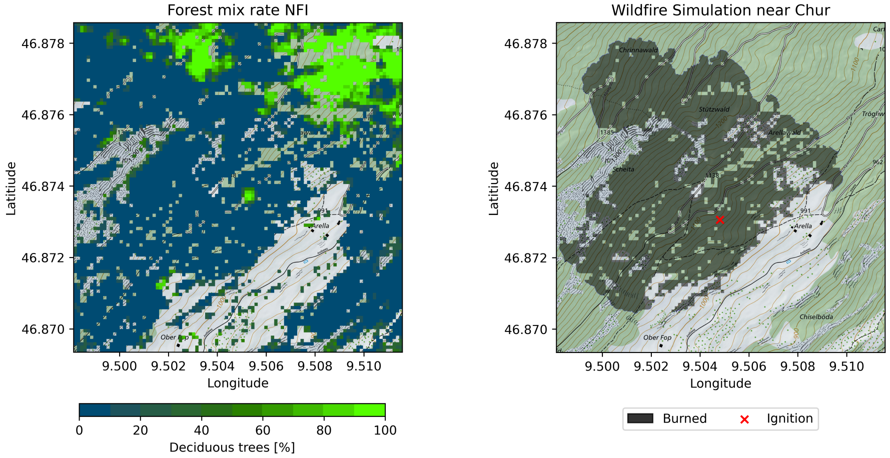
Fig. 4: Comparison of Cell2Fire (a) and V2 (b) to FARSITE on heterogeneous fuels. The landscape has no slope, and wind is not included.

4.4 Proof of Concept Simulation

The proof of concept simulation was run on real data to show the general performance of the model without optimization. The landscape used for this simulation consists of a single *swissALTI3D* [8] chunk with an area of 1 × 1 km and a cell resolution of 0.5 m, resulting in a 2000×2000 cell simulation grid. The according forest mix rate [7], which is used to determine which cells are capable of burning, can be seen in Fig. 5a.

As it has been found to perform best, Version 2 was used for this simulation. Simulating the fire for $t = 6$ h took 195 s $\approx$ 3.25 min on the specified hardware, while only exporting after the simulation has finished. Figure 5b shows the result of the proof of concept simulation.

ICCS Camera Ready Version 2026
To cite this paper please use the final published version:
DOI: `10.1007/978-3-032-29924-6_1`



(a) Forest mix rate around Chur, Switzerland

(b) Proof of concept simulation around Chur, Switzerland

Fig. 5: The forest mix rate (a) and the result of the proof of concept simulation (b) around Chur, Switzerland.

5 Discussion

The results show that V2 significantly outperforms the baseline and V1 when tested under ideal conditions. This improvement is mostly attributed to the exact time of arrival calculation in the local propagation logic. Version 2 also performs significantly better in matching the shape and size of the expected fire perimeter, which results in a higher recall score, especially important for wildfire simulation models [21]. In addition, the model remains stable in the F_1-Score metric, when the time step size is increased, allowing the model to use much coarser time steps while achieving similar results to the baseline model. While model performance scales with the user-defined export frequency, the computational overhead remains manageable because expensive perimeter calculations are triggered only during export events.

This study showed that the novel extraction of a vector perimeter from local fire spread ellipses can improve the accuracy of raster-based simulators. To the best of the authors knowledge, this is the first hybrid model that extracts the vector-based perimeter from the raster-based simulation in addition to the exact time of arrival calculation, while preserving parallelisability. Although the perimeter extraction alone does not improve the results significantly, the combination with the calculation of the exact time of arrival leads to much better results. Crucially, these advances are achieved without breaking the inherent parallelisability of raster-based simulations, while further avoiding complex vector-based crossover removals.

ICCS Camera Ready Version 2026
To cite this paper please use the final published version:
DOI: 10.1007/978-3-032-29924-6_1

5.1 Interpretation and Implications

The work confirms the conclusion reached by [21] about the effectiveness of the hybrid approach. They found that their hybrid model achieved both promising accuracy as well as the computational performance required for faster-than-real-time simulations in the operational context.

After a careful review of the original paper and source code of Cell2Fire, it seems that the model does not use an exact time of arrival calculation similar to this work, but instead relies on small time steps to achieve state-of-the-art accuracy of over 90 %. This aligns with the conducted time step parameter study, which showed that the models perform similar on small time step sizes.

These results have both theoretical and practical implications. It is shown, that existing models can be extended to be using the calculation of the exact time of arrival. As this extension has the possibility to drastically improve the time step size required for accurate simulations, it also has implications for practical use. The model achieves faster-than-real-time performance on a 2000 × 2000 grid using a single-threaded implementation on consumer-grade hardware. Scalability tests on the same hardware demonstrate that a 7-day wildfire event can be simulated in less than real-time even on 10000 × 10000 grid [in 24 minutes] and 20000 × 20000 grid [in 40 minutes]. Beyond these dimensions, performance was limited by available RAM and storage capacity rather than computational throughput. The current implementation has not been extensively optimized for sequential execution nor parallelized. These results highlight the significant potential for even greater acceleration in an optimized or parallelized version of the approach.

5.2 Limitations

The scope of this research excluded many different wildfire growth features, which would be required for operational simulations. This includes the integration of different fire behaviour models apart from surface fires, the inclusion of suppression activities, and the effects of weather. The combination of these limitations excludes the developed model from being used apart from experimental studies, and also makes evaluating the model performance with real-world scenarios a difficult task.

The choice of expanding an existing model resulted in better comparability and faster development, but it also includes the assumptions of the extended Cell2Fire model. The assumption that may affect the results of this study the most is that the ROS values of the burning cell are used until the fire reaches the centre of the neighbouring cells [14]. This can result in distorted perimeters, especially when using cell resolutions of 25 m.

The new model performs particularly well when using large time step sizes. This assumes, however, that all the environmental influences on fire behaviour (except fuel model) remain constant during this time step. This results in a situation where wildfires in fast-changing weather environments can only benefit from the exact time of arrival calculation when the fire can spread to a

ICCS Camera Ready Version 2026
To cite this paper please use the final published version:
DOI: 10.1007/978-3-032-29924-6_1

neighbouring cell during constant weather influences. Consequently, the model reverts to the Cell2Fire functionality due to smaller time steps required. Besides that, the model continues to exhibit clear distortions along the flanks of the fire perimeter, highlighting opportunities for further improvement.

Other limitations include the lack of a direct comparison with FARSITE in realistic wildfires, which is essential for building trust in the model [15].

Despite these limitations, the results still remain valid. Furthermore, the issues related to the assumption that fire spread depends solely on the current cell environment, as well as the need to reduce time step size due to rapidly changing weather conditions, are less critical within high resolution environments.

5.3 Future Work

To transition the current model into a robust operational tool, several functional extensions are planned. These include integrating more detailed surface fire behaviour models, accounting for crown fire transitions and spotting phenomena, and coupling the system with dynamic weather data. Furthermore, we aim to incorporate the specialized burned cell conditions utilized in Cell2Fire. Beyond these practical considerations, future research will explore the structural advantages of the Pyros architecture. A key distinction of Pyros is the use of vector-based ignition points rather than fixed cell centres. Expanding this feature would allow the model to bypass the limited spread directions inherent in traditional raster-based simulators, potentially enhancing accuracy without sacrificing the efficiency of the underlying grid. Finally, while the current implementation demonstrates strong sequential performance, parallelization of the propagation logic will be explored to enable even faster simulations.

5.4 Conclusion

A new hybrid wildfire growth model tailored to the environmental conditions found in Switzerland was developed. By extending the already performant Cell2Fire model, the new model significantly improved the fire perimeter predictions on idealized fires, while allowing for much larger time step sizes with minimal accuracy loss.

Although the current model excludes several critical features such as crown fire behaviour, spotting, suppression activities, and weather coupling, it still provides a foundation for further development of wildfire modelling in Switzerland.

Looking forward, the integration of the excluded features describes the most critical part, next to the implementation of parallel computation techniques, to make the model not only usable but future proof. Given the rising threat of wildfires in Switzerland this work represents a crucial step in providing the computational resources required to support effective decision-making and management strategies for Swiss authorities.

ICCS Camera Ready Version 2026
To cite this paper please use the final published version:
DOI: 10.1007/978-3-032-29924-6_1

References

1. Bardsley, A.M., Bardsley, D.K., Conedera, M., Pütz, M., Robinson, G.M., Weber, D.: Wildfire, Environmental Risk and Deliberative Planning in the Locarnese Region of Switzerland. Environmental Management **68**(6), 785–801 (Dec 2021). https://doi.org/10.1007/s00267-021-01523-5, `https://doi.org/10.1007/s00267-021-01523-5`
2. Byram, G.M.: Combustion of forest fuels. In: Davis, K.P. (ed.) Forest fire: control and use, pp. 61–89. McGraw-Hill, New York, NY (1959)
3. Chen, H., Zhang, W., Sheng, L.: Canadian record-breaking wildfires in 2023 and their impact on US air quality. Atmospheric Environment **342**, 120941 (Feb 2025). https://doi.org/10.1016/j.atmosenv.2024.120941, `https://www.sciencedirect.com/science/article/pii/S1352231024006162`
4. Conedera, M., Feusi, J., Pezzatti, G.B., Krebs, P.: Linking the future likelihood of large fires to occur on mountain slopes with fuel connectivity and topography. Natural Hazards **120**(5), 4657–4673 (Mar 2024). https://doi.org/10.1007/s11069-023-06395-y, `https://doi.org/10.1007/s11069-023-06395-y`
5. Duff, T.J., Chong, D.M., Tolhurst, K.G.: Indices for the evaluation of wildfire spread simulations using contemporaneous predictions and observations of burnt area. Environmental Modelling & Software **83**, 276–285 (Sep 2016). https://doi.org/10.1016/j.envsoft.2016.05.005, `https://www.sciencedirect.com/science/article/pii/S1364815216301360`
6. Faranda, D., Alvarez-Castro, M.C., Alberti, T., Cazzaniga, G.: March 2025 Japan and South Korea wildfires have been fueled by meteorological conditions likely strengthened by human-driven climate change (Mar 2025). https://doi.org/10.5281/zenodo.15083384, `https://doi.org/10.5281/zenodo.15083384`
7. Federal Office for the Environment FOEN: Forest mix rate NFI (Oct 2023), `https://www.geocat.ch/geonetwork/srv/eng/catalog.search#/metadata/b07a4589-159b-4c3a-b1e7-dbdad11f7e62`
8. Federal Office of Topography swisstopo: swissALTI3D (Aug 2024), `https://www.swisstopo.admin.ch/de/hoehenmodell-swissalti3d`
9. Finney, M.A.: FARSITE: Fire Area Simulator-model development and evaluation. Tech. rep., U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station (1998). https://doi.org/10.2737/rmrs-rp-4, `http://dx.doi.org/10.2737/RMRS-RP-4`
10. G. D. Papadopoulos, F. -N. Pavlidou: A Comparative Review on Wildfire Simulators. IEEE Systems Journal **5**(2), 233–243 (Jun 2011). https://doi.org/10.1109/JSYST.2011.2125230
11. Ghisu, T., Arca, B., Pellizzaro, G., Duce, P.: An optimal Cellular Automata algorithm for simulating wildfire spread. Environmental Modelling & Software **71**, 1–14 (Sep 2015). https://doi.org/10.1016/j.envsoft.2015.05.001, `https://www.sciencedirect.com/science/article/pii/S1364815215001322`
12. Mark Finney, Charles McHugh: FlamMap (Aug 2024), `https://research.fs.usda.gov/firelab/products/dataandtools/flammap`, computer Software, Version 6.2
13. Miller, J., Böhnisch, A., Ludwig, R., Brunner, M.I.: Climate change impacts on regional fire weather in heterogeneous landscapes of central Europe. Natural Hazards and Earth System Sciences **24**(2), 411–428 (2024). https://doi.org/10.5194/nhess-24-411-2024, `https://nhess.copernicus.org/articles/24/411/2024/`

ICCS Camera Ready Version 2026
To cite this paper please use the final published version:
DOI: 10.1007/978-3-032-29924-6_1

14. Pais, C., Carrasco, J., Martell, D.L., Weintraub, A., Woodruff, D.L.: Cell2Fire: A Cell-Based Forest Fire Growth Model to Support Strategic Landscape Management Planning. Frontiers in Forests and Global Change **4** (2021), `https://www.frontiersin.org/journals/forests-and-global-change/articles/10.3389/ffgc.2021.692706`
15. Peterson, S.H., Morais, M.E., Carlson, J.M., Dennison, P.E., Roberts, D.A., Moritz, M.A., Weise, D.R.: Using HFire for spatial modeling of fire in shrublands. Tech. rep., U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station (2009). https://doi.org/10.2737/psw-rp-259, `http://dx.doi.org/10.2737/PSW-RP-259`
16. Qiu, M., Chen, D., Kelp, M., Li, J., Huang, G., Yazdi, M.D.: The rising threats of wildland-urban interface fires in the era of climate change: The Los Angeles 2025 fires. The Innovation **6**(5) (May 2025). https://doi.org/10.1016/j.xinn.2025.100835, `https://doi.org/10.1016/j.xinn.2025.100835`, publisher: Elsevier
17. Sullivan, A.L.: Wildland surface fire spread modelling, 1990-2007. 1: Physical and quasi-physical models. International Journal of Wildland Fire **18**(4), 349–368 (2009), `https://doi.org/10.1071/WF06143`
18. Sullivan, A.L.: Wildland surface fire spread modelling, 1990-2007. 2: Empirical and quasi-empirical models. International Journal of Wildland Fire **18**(4), 369–386 (2009), `https://doi.org/10.1071/WF06142`
19. Sullivan, A.L.: Wildland surface fire spread modelling, 1990-2007. 3: Simulation and mathematical analogue models. International Journal of Wildland Fire **18**(4), 387–403 (2009), `https://doi.org/10.1071/WF06144`
20. Tymstra, C., Bryce, R., Wotton, B., Taylor, S., Armitage, O.: Development and structure of Prometheus: the Canadian wildland fire growth simulation model. Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre, Information Report NOR-X-417.(Edmonton, AB) (2010)
21. Voltolina, D., Cappellini, G., Apuani, T., Sterlacchini, S.: Pyros: a raster–vector spatial simulation model for predicting wildland surface fire spread and growth. International Journal of Wildland Fire **33**(3) (2024). https://doi.org/10.1071/WF22142

ICCS Camera Ready Version 2026
To cite this paper please use the final published version:
DOI: `10.1007/978-3-032-29924-6_1`