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A Comparison between FARSITE and FOREFIRE

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Abstract. Accurate fire spread modeling is essential for understanding and mitigating the impacts of wildfires. This study compares two fire spread models, FARSITE and FOREFIRE, by reconstructing the 2022 wildfire in El Pont de Vilomara, Spain. Both models use the Rothermel rate of spread (ROS) equation to model fire behavior, however, FOREFIRE employs a simplified fuel classification system, which may impact the accuracy of its predictions. Our analysis evaluates fire spread predictions in 0D (ROS), 2D (fire perimeter), and 3D (plume dynamics) simulations. Results show that FARSITE underestimates fire propagation, while FOREFIRE overestimates it, both requiring ROS adjustments to match observation. The coupled FOREFIRE-MesoNH require also ROS adjustment but better incorporates fire behavior representation.

1. Introduction

Wildfires are among the most destructive natural disasters, causing significant ecological, economic, and societal impacts [1, 2]. Predicting and managing these events is crucial for minimizing damage and improving response strategies, with fire spread modeling playing a key role [3]. These models guide decision-making in areas like resource allocation, evacuation planning, and land management [4]. However, the complexity of fire behavior, influenced by factors such as fuel composition, weather, and topography, poses significant challenges for modelers, as outlined since the foundational work of Rothermel et al. [5].

Fire spread modeling is used in two primary modes: predictive and reconstruction. In predictive mode, models forecast fire behavior with limited initial information, often in operational fire response or fuel management

In this work, we compare the FARSITE and FOREFIRE models in reconstruction mode using a real-case wildfire scenario, analyzing simulations across different levels of complexity: from 0D (rate of spread), to 2D (fire spread), and 3D (plume dynamics). FARSITE is widely regarded as a reference model for operational fire behavior simulation, extensively used and validated in the fire science community. FOREFIRE, by contrast, represents a more recent, open-source alternative that offers greater versatility and modularity, making it well-suited for research and integration with diverse data sources. This comparison allows us to assess the performance and adaptability of a traditional operational tool versus a modern, flexible modeling framework. Benchmarking of fire model is not often conducted systematically, primarily due to the diversity of fire models that are based on different theoretical assumptions and on different input data (*e.g.* fuel models, weather parameters). These discrepancies make direct comparisons challenging. The 3D analysis is conducted only with FOREFIRE, as it is capable of operating within a coupled fire-atmosphere system using MesoNH [6]. The objective is to compare the performance of FARSITE and FOREFIRE, examine their differences, and highlight how model tuning parameters influence the accuracy of fire event reconstructions. The paper is organized as follows: we first describe the real-world case study, then present the methodology, followed by a discussion of the results.

2. Fire Scenario

The case study for this work is the wildfire event that occurred on July 17, 2022, in El Pont de Vilomara, Catalonia, Spain. The fire burned approximately 1,743 hectares of vegetation between 12:00 and 18:00 UTC.

Based on GFAS FRP data [7], this fire contributed 59% of Catalonia's fire emissions between April 1 and September 30, 2022. Ambient atmospheric conditions were simulated using MesoNH [6], forced by ECMWF reanalysis. The operational report (GRAF) indicates a southerly wind at 15 km/h. Fuel maps follow Scott and Burgan's model [8], sourced from PREVINCAT [9].

VIIRS imagery (Fig. 1) shows a southward plume from 12:00 UTC, despite southerly surface winds. A strong plume core and possible pyrocumulus formed at 12:00 UTC, dissipating by 13:00 UTC.

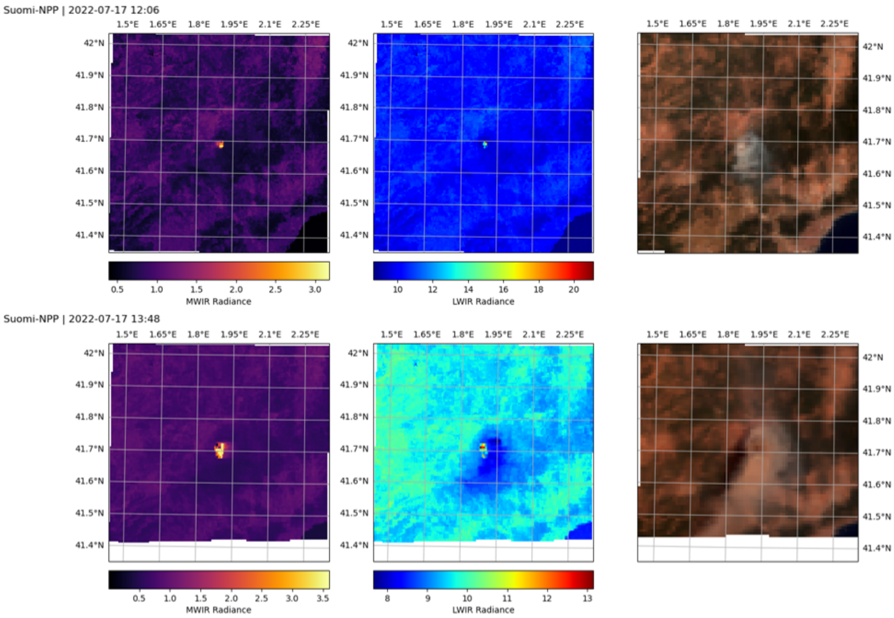

Figure 1. Two VIIRS overpasses of the fire of El Pont de Vilomara in Catalunya, Spain. Each row displays Medium-Wave Infrared (MWIR), Long-Wave Infrared (LWIR), and Visible bands for 12:06 and 13:48 UTC.

3. Methodology

As previously mentioned, this study employs two fire spread models: FARSITE [10] and FOREFIRE [11]. FARSITE is a widely used wildfire simulation model. it models wildfire behavior by incorporating factors such as fuel type, topography, and weather. FOREFIRE is essentially a solver for fire spread models. Originally based on the model of Balbi et al. [12], it can also accept any fire spread model if an associated fuel model is provided. A strength of FOREFIRE is that it can run as a standalone model or coupled with the atmospheric model MesoNH [6]. In this case, it allows for considering the effects induced by fires on the atmosphere and the feedback impact of these effects on fire propagation [11].

3.1. Rate of Spread Model: The Rothermel Model

We used in FOREFIRE and FARSITE the same semi-empirical equations of Rothermel [3]. However, although based on the same equations, the two approaches are not using the same input fuel models. FARSITE is based on the five-class fuel model proposed by Scott and Burgan [8], which categorizes dead fuels into three different size classes (1-hour, 10-hour, and 100-hour) and includes live fuels (herbaceous and woody). Each fuel class require key characteristics such as load and surface-to-volume ratio, as well as additional model parameters like fuel depth, dead fuel extinction moisture, and specific heat content. Using this data, along with input parameters such as wind speed at 20 feet and fuel moisture for each class, the Rothermel model equations calculate a ROS value for a given fuel model (see [3] for more details). This is done by first evaluating the fuel characteristics of the heterogeneous mixture created from the combination of the five classes. In FOREFIRE a simplification is applied within the Rothermel model equation, where only the 1-hour fuel class is considered, assuming that the 1-hour fuel class is the primary contributor to fire spread [13].

3.2. Fire Spread model: FARSITE, FOREFIRE

In FARSITE, the spatial integration of the fire front spread is based on a Lagrangian approach, where the fire front is represented by markers that are advected over fixed time steps. While the rate of spread is derived from the Rothermel model, the direction of propagation is determined at each marker using the Richards model [14]. This model applies the Huygens principle and assumes ellipsoidal propagation of the fire front.

Similarly, FOREFIRE uses a Lagrangian approach but with an adaptive time step. In FARSITE, tracking the fire front is computationally expensive, particularly in situations where the fronts merge [10]. However, with the Lagrangian approach, it is less dependent on the resolution of input data (e.g., wind, fuel) and imposes fewer constraints on a global time step. In FOREFIRE, the direction of propagation is assumed to be normal to the front. This normal direction is computed using the position of the nearest neighbor markers. Although FOREFIRE can support several ROS models, here we only use the Rothermel 1-hour fuel class.

To perform the simulations with both simulators, the wind was spatially averaged from uncoupled MesoNH simulations. The moisture was set to the low setting of Scott and Burgan [8] and integrated with the Nelson model [15] in the case of FARSITE, while for FOREFIRE, it was integrated with the Von Wagner model [16].

Spotting probability is not set in FARSITE for sake of comparison as this option is not available yet in FOREFIRE.

3.3. Fire-Atmosphere Coupled System: FOREFIRE-MESONH

While the FARSITE and FOREFIRE provide insights into fire growth, they do not account for the atmospheric feedbacks that can influence fire dynamics. To address this limitation, FOREFIRE was implemented in the MesoNH atmospheric model to form a coupled fire-atmosphere system [11] that integrates both fire spread, fire heat flux and the atmospheric processes that govern wind, temperature, and humidity, hence simulating the convection in the plume and feedback onto the wind at the fire front level. In this coupled system, the fire spread model uses simulated wind at the location of the fire front as input. A similar approach is implemented in WRF-Sfire [17], which also uses the Rothermel model equation to calculate the ROS. However, using local wind inputs with the Rothermel model contradicts one of its key assumptions, which is that in its original formulation, the wind input should come from ambient conditions.

4. Results

This section compares output from different level of fire spread (0D:local ROS, 2D:fire spread, 3D:fire spread coupled with the plume) for two models: FOREFIRE using the Rothermel model based on 1-hour fuel class, and FARSITE, version5. The model outputs are also compared with firefighter observation on a plume-driven event.

4.1. Rate of Spread model: Rothermel

Figure 2 compares the rate of spread for two Scott and Burgan [8] fuel models: GR1 (101) and SH5 (145), both of which are present in the El Pont de Vilomara fire. This comparison uses two different approaches: one used by FARSITE (solid line), which considers the 1-hour, 10-hour, and 100-hour fuel classes and includes live fuels (herbaceous and woody), and the one used by FOREFIRE (dashed line), which employs the 1-hour fuel class approach. It can be seen that these approaches lead to different ROS values across varying fuel moisture and wind speeds. The 1-hour approach in GR1 consistently overestimates, while SH5 shows wind velocity thresholds (1–20 mi/hr) that are absent in the full Rothermel model. The comparison highlights that the 1-hour approach significantly alters the behavior of the resulting 0D ROS.

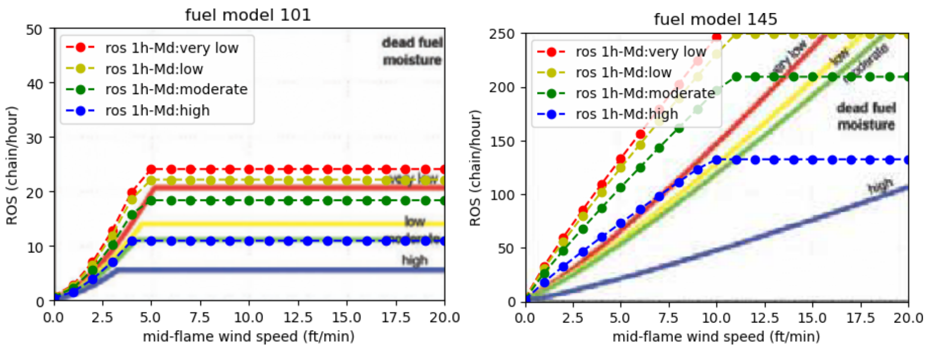

Figure 2. Rate of Spread for two Scott and Burgan fuel models [8] (GR1 and SH5) varying fuel moisture and mid-flame wind speed. The dashed lines represent computations for the 1-hour fuel class only, as done in FOREFIRE.

4.2. Fire Spread model: FARSITE, FOREFIRE

The FARSITE and FOREFIRE simulations are now compared using the ignition data from the firefighter report. The simulations are run for 2.5 h (until 13:30 UTC), corresponding to the time it took for the fire to reach the River Park community, located 3.2 km away. Figure 3 shows 30-min interval fire front from 12:00 to 13:30 UTC for FARSITE, along with three FOREFIRE simulations: the standard configuration, a run with a ROS adjustment of 0.2 (FOREFIRE "ROS Adjust"), and a simulation coupled with MesoNH, incorporating a ROS adjustment factor of 0.1 (FOREFIRE-MesoNH).

FARSITE clearly underestimates the ROS. Simulations of other fires in Catalonia using FARSITE have shown similar trends [18]. In contrast, FOREFIRE tends to overestimate the propagation. A ROS adjustement factor of 0.2 was applied to match the final forward spread after 2.5 h. In the two 2D approaches, the models show very different behavior when applied to the same fuel model map; the ROS adjustment factor can be used to optimized arrival time

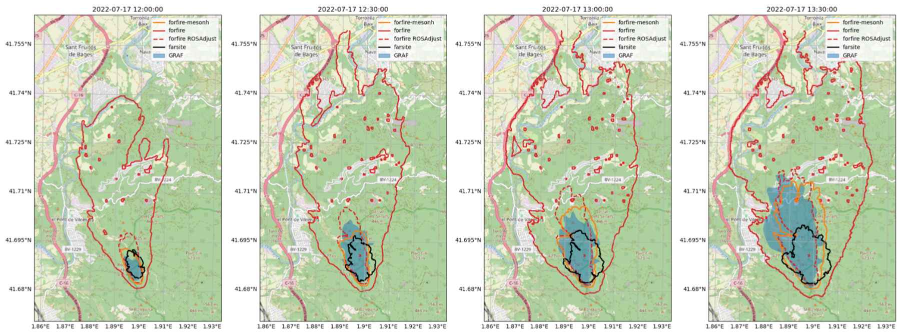

Figure 3. Fire front perimeters simulated for the El Pont de Vilomara fire using FARSITE and FOREFIRE with three different configurations, along with the real fire front from the firefighter report (GRAF).

at a given location (*i.e.* River Park, here), but it does not correct for fire behavior. Indeed, in the three first time shown on Fig3, FOREFIRE "ROS Adjust" remain ahead of the firefighter observation.

4.3. Fire-Amosphere Coupled System: FOREFIRE-MESONH

The last simulation FOREFIRE-MESONH is set with a ROS adjustment factor lower than in the 2D FOREFIRE "ROS Adjust" simulation. As the local wind at the fire front is increased by the convection triggered by the plume, FOREFIRE requires a lower ROS adjustment factor to match the arrival time at the community of River Park. However,in this case, the match during the 2.5-hr of propagation is improved.

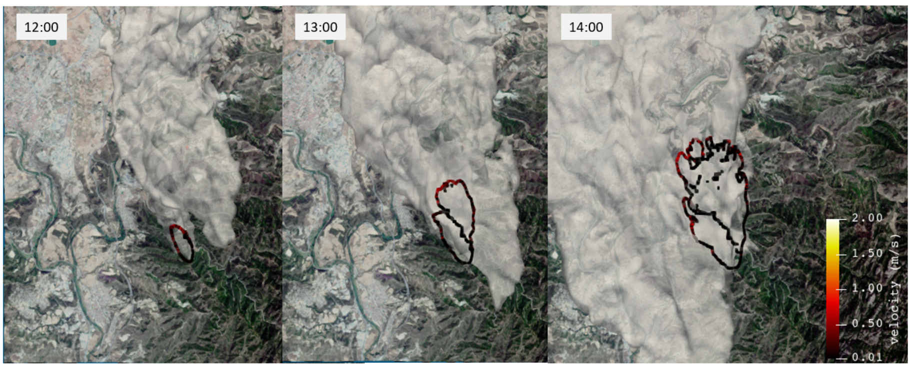

Figure 4. Nadir view of the isocontour of the passive tracer emitted in the coupled FOREFIRE-MesoNH simulation. The plume is shown in white while the fire front is represented by the FOREFIRE vertex colored with their respective ROS.

We also show in Fig 4 the plume evolution simulated by MesoNH. Using a passive tracer to visualize the plume, We employ a low iso-surface value to highlight the plume's horizontal motion, which matches the trend observed in the VIIRS overpasses. First, there is a spread towards the north, driven by the ambient surface wind, and then, after 13:00 UTC, a spread towards the south at higher altitudes when the smoke passes the boundary layer.

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5. Conclusion

By comparing FARSITE and FOREFIRE, the objective of this work is to highlight the need of further testing on the currently developed fire-atmosphere system. We show that using 0D implementation of Rothermel equations with a 1 fuel class does not hold the comparison with the full implementation (5 class) of the same equations. Furthermore, when run in 2D, ROS adjustment factor are necessary in both FOREFIRE and FARSITE to match observation in our test case. However the correction cannot correct for local adjustment of the fuel model, it can only correct for local arrival time. It would need to be constantly estimated during the model integration. The coupled system however shows a better adaptation to ROS adjustment that would need to be investigated further.

Acknowledgments

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