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# QUIC-Fire: Initial capabilities of a fast-running simulation tool for prescribed fire applications

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**Abstract**

Prescribed fire is increasingly being looked to as a tool that can support land and fire managers in their efforts towards ecological sustainability and wildfire risk management. As prescribed fire use is considered for treatment of more acres and in more complex settings, practitioners are having to work harder to meet their expanding treatment goals in a safe and environmentally responsible manner. In the context of a prescribed fire, the role of multiple ignitions and complex fire geometries depends heavily on feedbacks between the fire and atmosphere and accentuates the need for explicit representation of these processes in any modeling tools that are to be used to support prescribed fire managers. Computational fluid dynamics models like FIRETEC and WFDS are inherently capable of representing this interaction, but they are too computationally expensive for widespread uses by practitioners for exploration and analysis. We have developed a new simulation tool called QUIC-Fire to capture these fire/atmosphere feedbacks while being orders of magnitude less computationally expensive by coupling the fast-running 3-D rapid wind solver QUIC-URB to a physics-based cellular automata fire spread model Fire-CA. Here we describe some of the model basics and provide initial demonstration capabilities of a new fast-running modeling tool, QUIC-Fire, that can be applied to prescribed fire planning. QUIC-Fire provides a self-determining fire prediction capability that represents the critical coupled fire/atmosphere feedbacks at scales relevant for prescribed fire. Although, the development of this model is in the nascent stages, initial results show an encouraging capability to capture basic trends in fire behavior, response of fire spread to size of fire, consumption of canopy fuels in prescribed fire scenarios, interaction between multiple firelines and response to heterogeneity in vegetation. Its ability to model response to both ignition patterns and a temporally and spatially variable fire environment without computational expense of CFD solutions is encouraging.

## 1. Introduction

Prescribed fire is one option that land and fire managers can use in their efforts towards wildfire risk management and ecological sustainability and thus a variety of programs are working to escalate its use. Intentional ignitions are used to manage 5 million hectares annually in the US (Melvin, 2015) with several millions more burned globally (Bond and Keeley, 2005; Guyette et al., 2017; Ichoku et al., 2008). As prescribed fire use is considered for treatment of more acres and in more complex settings, practitioners are faced with the challenge of meeting their expanding treatment goals in a safe and environmentally responsible manner. Planning prescribed fire practices and defining their prescription windows to meet objectives depends on anticipating the fire's response to variation in fuels and weather conditions (Chiodi et al., 2018; O'Brien et al., 2018; Wade et al., 1989). Thus, it is desirable to have simulation tools that can be used to assist with planning and exploration of potential prescribed fire scenarios.

## 2. Models Applied to Prescribed Fires

Predicting prescribed fire behavior can depend on factors that are not as significant in rapidly spreading or intense wildfire, which have been the focus of much wildfire modeling to date. One factor that complicates the prediction of prescribed fire behavior compared to wildfire scenarios is the significant influence of the rates and patterns of ignition on ensuing fire behavior. The role of multiple ignitions and complex fire geometries, which are present in many prescribed fire scenarios, depends heavily on feedbacks between the fire and atmosphere, accentuates the need for explicit representation of this coupling in any such simulation tools that are to be used to support prescribed fire managers. Also, the interaction between the fire environment and practitioner-designed ignition practices depends on landscape-scale fuel, weather, and topographic conditions as well as their localized spatial and temporal variability (Canfield et al., 2014; Furman, 2018).

The absence of strong driving conditions such as strong winds, steep slopes, or extremely low fuel moistures increases the challenge of predicting prescribed fire behavior (Linn et al., 2021) In the absence of such strong drivers the three-dimensional heterogeneities of the forest structure increase in importance. Additionally, since the metrics for success of a prescribed fire often depend on meeting ecological or fuel reduction objectives without breaching safety constraints the interaction between the fire and the heterogeneities vegetation structure is important. Thus, an important characteristic for simulation tools focused on supporting prescribed fire planning is the ability to capture the interaction between three-dimensional heterogenous forest structure, and fire behavior.

Many fire behavior models have been developed to predict fire spread and energy release using a variety of approaches ranging from empirical one-dimensional spread models to three-dimensional CFD models (Sullivan, 2009a; Sullivan, 2009b), but ultimately all wildland fire models must balance representing the complexity of fire-fuel-atmospheric feedbacks and the speed of predictions (Hilton et al., 2018). Firefighter safety and rapid assessments of fire spread have dominated the objectives for much of the wildland fire modeling to date, leading to development of tools producing rapid outputs for common or dangerous wildland fire scenarios. Unfortunately, the speed of these tools is often achieved by eliminating complexity and computational cost, which can frequently means reduction of generality. Simplifications are often made to the representation of the coupling between the fire and atmosphere to fit the conceptual model of a free-burning head fire. This conceptual paradigm does not always capture phenomena associated with the complex fire geometries and multiple fires that exist in prescribed fire scenarios. These tools often do not explicitly represent the heterogeneity of the fuel or three-dimensional structure of the vegetation and thus make assumptions about the structure. Although, these simplifications are often acceptable for many intense wildfire scenarios they ignore the sensitivity of prescribed fires to subtle changes in fire environment. Computational fluid dynamics (CFD) models like FIRETEC (Linn et al., 2002 and WFDS (Mell et al., 2007) are inherently capable of representing the sensitivity of fires to their environment and important interactions at scales relevant to prescribed fires, but they are primarily research tools and are currently are too computationally expensive for widespread use by practitioners for exploration and analysis.

Tools are now being developed with more specific intent of supporting prescribed fire planning. QUIC-Fire (Linn et al., 2019) is an example of a new simulation tool designed to capture fire/atmosphere feedbacks that are pertinent to prescribed fires while being orders of magnitude less computationally expensive than CFD tools. QUIC-Fire provides a self-determining fire prediction capability that represents the critical coupled fire/atmosphere feedbacks at scales relevant for prescribed fire. This was accomplished by exploiting the capabilities of the QUIC-URB wind field solver (Pardyjak and Brown, 2003; Singh et al., 2008) coupled with a new CA-based fire spread model, referred to here as FIRE-CA. QUIC-URB is a fast-running wind field solver that was originally designed for computing flow fields around buildings in urban settings (Pardyjak and Brown, 2003). Although, the development of QUIC-Fire is in the nascent stages, initial results show an encouraging capability to capture basic trends in fire behavior, response of fire spread to size of fire, consumption of canopy fuels in prescribed fire scenarios, interaction between multiple firelines and response to heterogeneity in vegetation. Its ability to model response to both ignition patterns and a temporally and spatially variable fire environment without computational expense of CFD solutions is encouraging.

## 3. Looking forward

Significant efforts to refine this simulation tool are expected to improve its ability to meet the needs of prescribed fire practitioners including additional smoke and fire effects capability. It is also extremely important to continuously assess strengths and weaknesses of this tool, as with all models, through comparison against observations and the expectations of experienced prescribed fire managers. These assessments can be challenging because of the complexity of many prescribed fire scenarios and the dependence of prescribed fire behavior on heterogeneity of the fire environment, but they are crucial for identifying fire regimes warranting increased confidence or refinement in the model. When examining the behavior of models like QUIC-Fire is important to look beyond spread rate to broader context of fire and smoke behavior.

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