

# Simulating fire spread in a community using an agent-based model

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## 1. Introduction

This study employed an agent-based model to simulate fire spread in a community. The simulation model considers four factors: ignition point, heat release rate, road density, and wind effect based on literature (Albini 1976; Anderson 1968; Finney 2010; Anderson 1983). The study area is located in City of Avondale in Georgia, United States, with approximate size of 0.8 square kilometers (fig.1). This community was chosen because it has a mixture of forest and residential areas, therefore it may provide insights into fire spreading in different settings. The satellite image of the study area was obtained from Google Earth and the simulation model was developed in Netlogo.



Figure 1. Study area

## 2. Methods

Agent-based model was used to simulate fire spreading by interacting fire agents with virtual environment which is consistent with literature (Bonabeau 2002; Carmel 2009). The simulation was based on physical fire behaviors (Himoto 2008), and accordingly agents make decision combining ignition point and heat release rates of fuels to determine whether the fire is able to spread. We then propose nine scenarios with various settings of selected factors to examine the

impact of the factors on fire spread. The spread trend simulation then generates a map of burnt areas describing the trend of fire spread. When a fuel was ignited in the model, its burning time will be recorded. By mapping fuels' burning time, we can then determine the direction and trend of fire spread.

### 3. Agent-based modeling

Inspired by previous studies (Waters 2002; Zhang 2007; Yassemi 2008; Stavrakakis 2009; Zhao 2010), an agent-based simulation model, which included a virtual environment and agents called "ember", was developed to simulate a community fire. A virtual environment was established consisting of house, wood, lawn, road, and barren areas in the study community. Houses and woods are the major fuel sources. The ember agents were defined as the edge of fire which is used to determine whether fire meets the physical requirement for spreading. An ember agent makes two decisions: determining whether the fire could be maintained and whether the ignition point of un-ignited fuel has been reached.

The heat release rate was derived by equation (1) from Nelson's study (1986).

$$Q = \alpha \times t^2 \quad (1)$$

where  $Q$  is heat flux ( $\text{kw} \cdot \text{m}^{-2}$ ) and  $t$  is time (s). The parameter  $\alpha$  is a constant value and was obtained from previous fire experiments (Hao 1992; Madrzykowski 2008). This study used minimum critical heat flux as the ignition point of a fuel. When an un-ignited cell is exposed to a constant minimum heat flux, the fuel cell will be ignited (Babrauskas 2001).

The wind effect is related to parameter  $\alpha$  for simulating wind's influence on heat releasing (Meroney 2011). We implemented eight wind directions in the model. For the fire starting location (i.e., fire source cell), road density will be calculated to describe the continuity of fuels. Holborn et al. (2004) suggested the average time from occurrence of fire to the arrival of fire fighters is nearly 10 minutes. So we calculated road density by dividing the road area by 10-minute fire damage area for each fire starting location in this model.

### 4. Scenarios

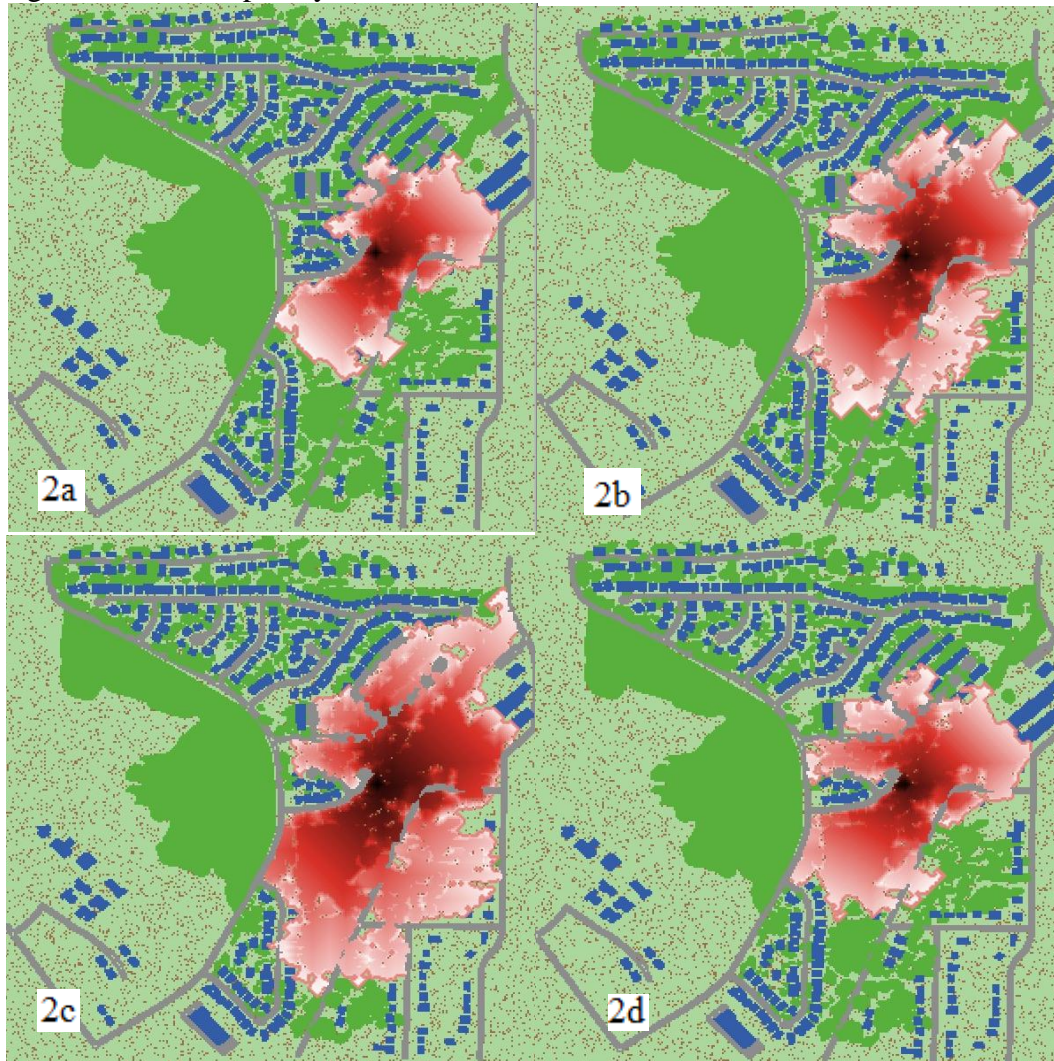
This study proposed nine scenarios (table 1). They reflect different settings of factors in order to gain insights into the impact of each factor on fire behaviors and final burnt area. Scenario A serves as the reference for other scenarios.

Scenario	Condition	H-ip ( $\text{kw} \cdot \text{m}^{-2}$ )	T-ip ( $\text{kw} \cdot \text{m}^{-2}$ )	H-a	T-a	R-d (%)	Wind
A	Reference	5.4	5.4	0.0264	1.1852	13	none
B	Low Ignition point	2.2	2.2	0.0264	1.1852	13	none
C	High heat release rate	5.4	5.4	0.1055	5.7292	13	none
D	East wind	5.4	5.4	0.0264	1.1852	13	east
E	South wind	5.4	5.4	0.0264	1.1852	13	south
F	West wind	5.4	5.4	0.0264	1.1852	13	west
G	North wind	5.4	5.4	0.0264	1.1852	13	north
H	High density of road	5.4	5.4	0.0264	1.1852	24	none
I	Low density of road	5.4	5.4	0.0264	1.1852	10	none

Table 1. Nine Scenarios. H-ip, ignition point of house; T-ip, ignition point of tree; H-a, parameter  $\alpha$  of house; T-a, parameter  $\alpha$  of tree; R-d, Road density.

## 5. Results and Discussions

Scenarios' results (fig. 2) presenting the comparison of fire area (fig. 3) and average spread rate (fig. 4) showed all the four factors have critical impact on fire spread. First, a low ignition point in scenario B (fig. 2b) produced a larger fire range and a faster spread rate than that in scenario A (fig. 2a) because low criteria of ignition allow fuel to be ignited with low radiation of heat. Second, a higher heat release rate of fuel (fig. 2c) resulted in faster fire spreading and a larger damage area as a high heat release rate leads to high radiation of heat. Third, the presence of wind increased the fire range (fig. 2d – fig. 2g) given that it accelerated the heat releasing process and resulted in high radiation of heat. Wind also changed the fire spread trend in the wind direction. Last, road density affected fire spread from two aspects, shaping damaged area and interrupting the continuity of fuels (fig. 2h – fig. 2i). Scenario H produced a very small fire range, because the continuity of fuel has been interrupted by roads. Scenario I showed the resulting damaged area concentrating on the west forest land along the road, which showed that the damaged area was shaped by road distribution.





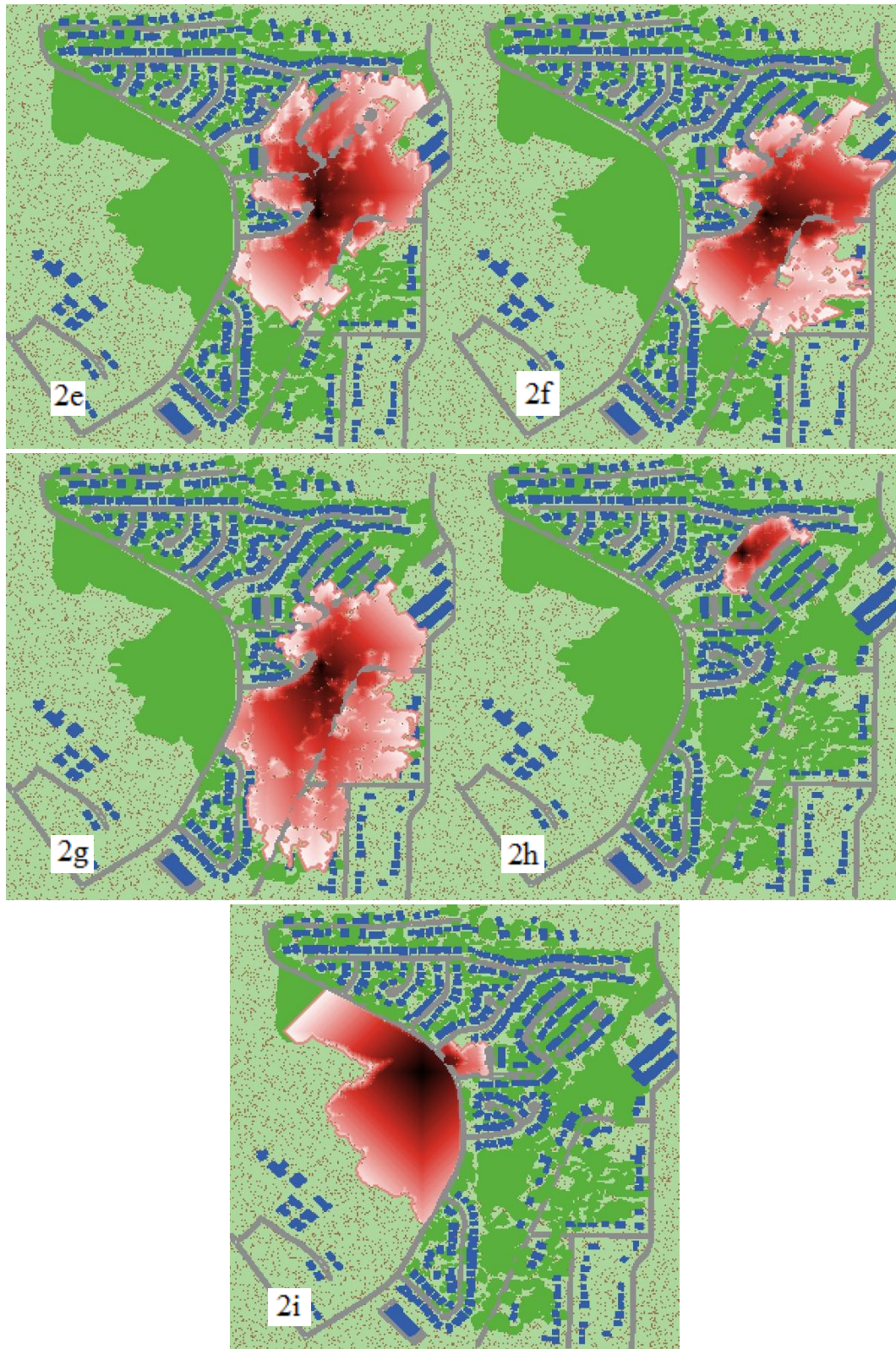


Figure 2. Results of scenarios. 2a – 2i represent results of scenario A to scenario I.

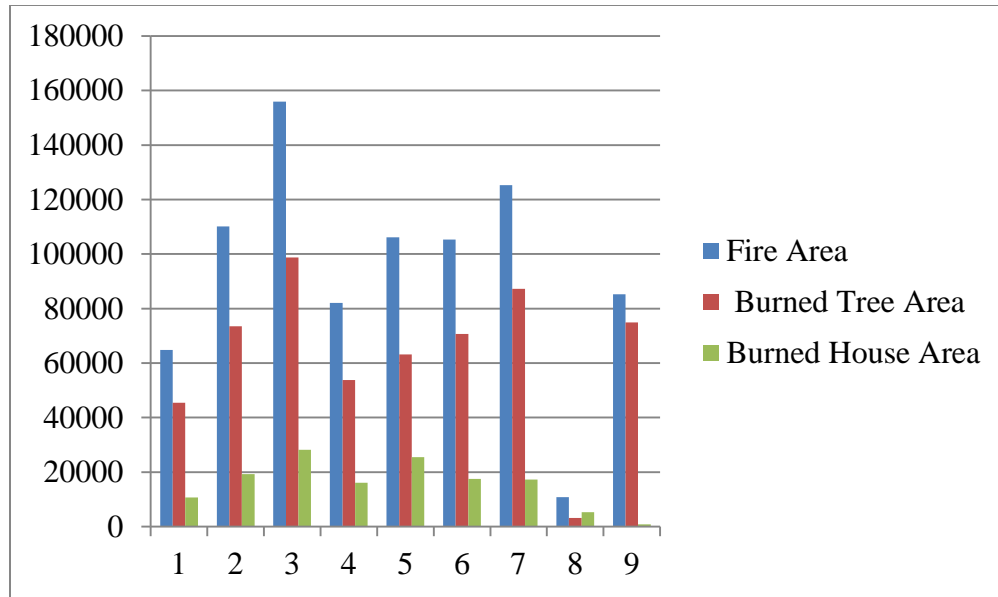


Figure 3. Fire-damaged area (m<sup>2</sup>) of the scenarios. Column 1-9 represents scenario A to I.

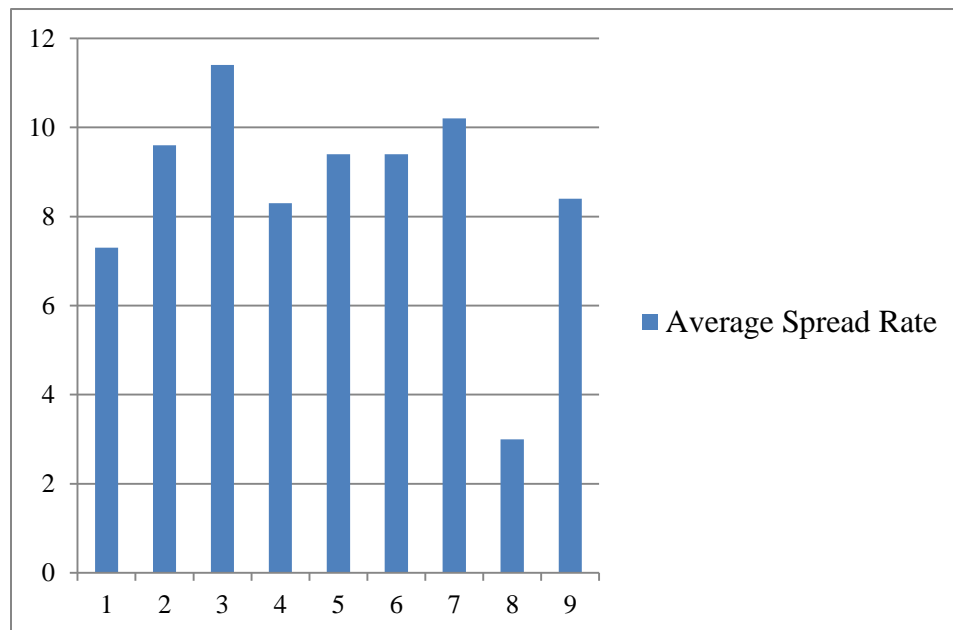


Figure 4. Average fire spread rate (m<sup>2</sup>/s). Column 1-9 represents scenario A to I.

In summary, ignition point and HRR play important roles in the variation of spread rate and fire area. Wind can largely change the spread trend of fire and enlarge the fire range. Road density has various impacts on fire spread. In most cases, the fire-damaged area was shaped by roads. When roads interrupt the continuity of fuel beds, fire could be contained in a limited range. This study demonstrates that agent-based modeling is an effective technique to investigate community fire spread and its influencing factors.

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