Software tools for wildfire monitoring

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Abstract

Phenomena in ecosystems such as forest fires, oil spills, tornados, etc., are complex processes both in time and space. Understanding their dynamics in order to predict their future states is a challenging procedure involving the propagation of several events concerning, e.g. the transfer of energy or material. A common solution used to study such phenomena is the utilization of discrete event models and simulators. Among the phenomena studied by researchers so far, of particular interest and importance, is the forecasting of forest fire propagation since life on earth is greatly depended on healthy forests. In this paper, we investigate simulator models applicable in forecasting forest fire propagation. These simulator models appear to be very useful and user friendly, and except for the investigation of a fire, they could also be used for teaching in a university lab.

Key Words: Wildfire, Event Propagation, Simulator Models, Teaching

1. Introduction

Understanding and quantifying the process of fire is critical for those seeking to manage fireprone ecosystems. The main parameters, such as fire intensity and rate of spread (ROS) have to be estimated accurately. Fire intensity is important as it determines the scorch height and thereby the amount of the plant canopy consumed, killed or unburnt, and ROS is equally important as it determines the time periods for which plants and animal will be subjected to lethally high temperatures [1]. Further, variables such as fuel moisture, fuel loading, wind velocity, relative humidity, slope, and solar aspect are all recognized as producing important effects on fire.

Wildland fire is the complicated combination of energy released (in the form of heat) in the process of combustion (primarily involving the oxidation of thermal decomposition products of vegetation) and the transport of that energy to surrounding unburnt fuel and the subsequent ignition of that fuel. The former is the domain of chemistry and occurs on the scale of molecules, and the latter is the domain of physics and occurs on scales ranging from millimeters up to kilometers. It is the interaction of these processes over the wide range of temporal and spatial scales involved in wildland fire that makes the modeling of wildland fire behavior such a difficult task.

Fons [2] was the first attempting to describe fire spread using a mathematical model. Despite the numerous publications in the literature, at present, no single comprehensive model of wildland fire behavior exists so far. This reflects a lack of knowledge regarding the physical and chemical processes as well as the topography and environmental factors and their interactions. Perry [3] comes to fill this gap by studying comparatively the existing models and simulators, pointing out their strengths and weaknesses and proposing appropriate improvements to support their performance.

Diffusion processes (oil spills, fire spread, insect infestation, etc.) are usually represented as partial differential equations (PDEs) that have to be discretized in the form of finite differences or finite elements. Starting with a PDE with derivatives in time and space dimensions, time and space are discretized. Three are the basic categories of discrete event modeling: i) Cellular Automata (CA), ii) DEVS (Discrete EVent System), and iii) a hybrid formalism of the two former categories Cell-DEVS (Cellular-DEVS). All these models are extensively examined and analyzed in the research papers [2,4], and in the references therein.

Sullivan [5,6] has attempted to provide a detailed overview of the various approaches of the last two decades (1990 – 2007) to predict the spread of wildland fire across the landscape.

Generally, fire models can be divided into three broad categories: physical and quasi-physical models [5]; empirical and quasi-empirical models [6]; and simulation and mathematical analogue models [4]. A **physical**

model is one that attempts to represent both the physics and chemistry of fire spread, a quasi-physical model attempts to represent only the physics, **an empirical model** contains no physical understanding at all, generally only statistical in nature, and a **quasi-empirical model** is one that uses some form of physical framework on which the statistical modeling is based. Many proposals on the two first categories have been proposed in the period that Sullivan examines. In this paper, we focus on the last category, i.e. simulation models, which are analyzed in the next sections, since we believe that it is closer to the engineering scope that a manager has to apply to handle efficiently a wildfire event, and because we believe that the simulator models can be introduced as a lecture in a lab of a department like the physics department.

To overcome the limitations of analytical models, much use has been made of simulation models to predict the growth patterns of wildland fires. Such models make use of computer graphics to produce a visual representation of the growth of a wildland fire event over a landscape. Fire behavior models using multi-dimensional theoretical wildfire spread models are being developed to predict rates of spread in complex environmental conditions varying spatially and temporally, introduced in the last decades.

The remainder of this paper is structured as follows. Wildfire simulation models are examined in the following section, while in section 3 the FARSITE simulator is evaluated. Concluding remarks are drawn in section 4.

2. Wildfire Simulators

Fire spread as a spatial phenomenon is strongly based on Geographic Information System (GIS) information, regarding the territory morphology. Numerous projects worldwide are under deployment to this target.

A running project is **Prometheus** [7], a Canadian national project with its last (open source) software release dated in May 2009. This is a deterministic fire growth simulation tool. It uses spatial fire behavior input data on topography (slope, aspect and elevation) and Fire Behavior Prediction (FBP) fuel types, along with weather stream and FBP fuel type lookup table files. The simulation code is written in Visual C++ and uses the Microsoft COM interface, while it supports 2D and 3D graphical interface. The software is user friendly and allows users to modify fuels and weather data, which are imported as ASCII files. A screenshot of the Prometheus simulator can be seen in figure 1.

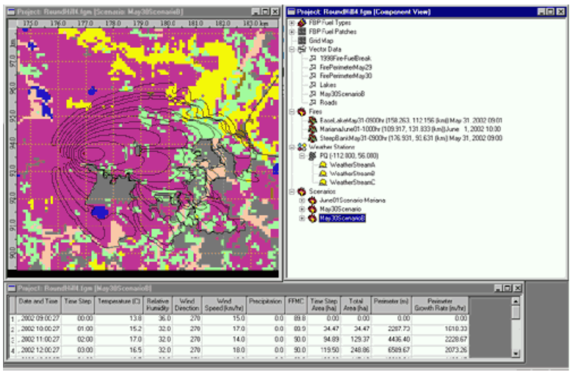

Fig. 1. Prometheus fire simulator

A tool for bushfire risk management model, **Phoenix** [8], is being developed in Australia. This simulation tool relates directly the impact of various management strategies to changes in fire characteristics across the landscape, and the nature of the impact on various values and assets in the landscape. Phoenix runs in an environment where it can respond to changes in conditions of the fire in addition to changes of fuel, weather and topographic conditions. An example of the Phoenix simulation tool is illustrated in figure 2.

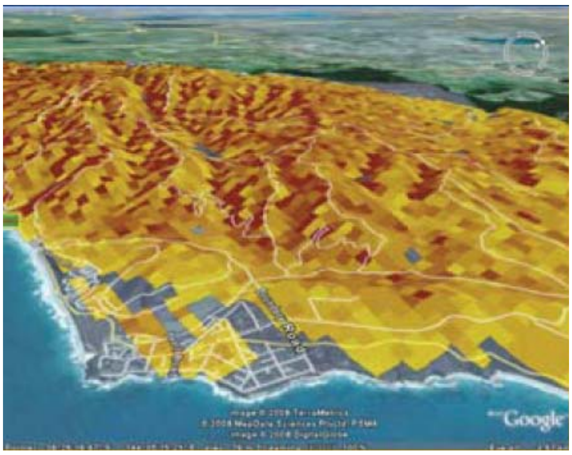

Fig. 2. Phoenix fire simulator

FireStation [9] implements Rothermel's fire spread model [10] in a raster-based GIS platform. The software implements a semi-empirical model for fire ROS, which takes as input local terrain slope, parameters describing fuel properties as well as the wind speed and direction. Fire shape is described with recourse to an ellipse-type model. Two different models are implemented for the simulation of the wind field. Both these models predict wind velocity and direction based on local observation taken at meteorological stations. The whole system is developed under a graphical interface, aiming at a better ease of use and output readability so as to facilitate its application under operational conditions. The workspace of FireStation simulator is shown in figure 3.

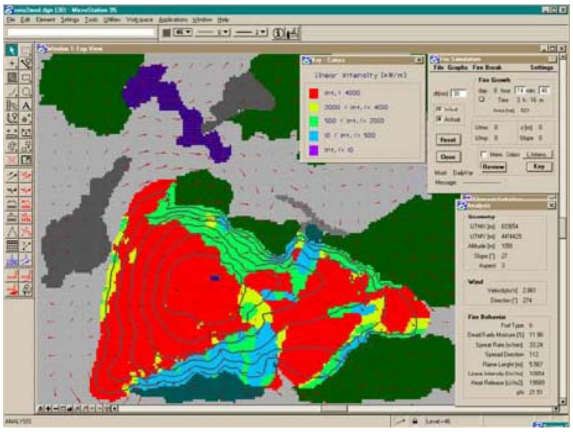

Fig. 3. FireStation fire simulator

HFire (Highly Optimized Tolerance Fire Spread Model) [11] is a raster-based spatially explicit model of surface fire spread through Southern California chaparral written in the C programming language. HFire can be used to predict the speed and direction of a fire spreading across the landscape in real-time. HFire can also be used for stochastic multi-year simulations of fire regime. The model is a product of research funded by NASA through the Southern California Wildfire Hazard Centre. A global sensitivity analysis (GSA) was conducted on HFire, a spatially explicit raster model developed for modeling fire spread in chaparral fuels, based on the Rothermel's spread equations [10]. The GSA provided a quantitative measure of the importance of each of the model inputs on the predicted fire size. This software is free for evaluation and also free for developers. A screenshot of the Hfire simulator can be seen in figure 4.

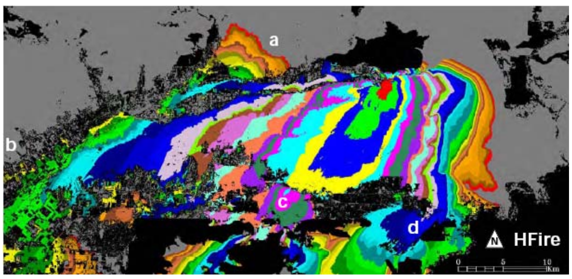

Fig. 4. HFire fire simulator

Last, but not least, comes **FARSITE** (Fire Area Simulator). FARSITE [12,13] is a model for spatially and temporally simulating the spread and behavior of fires under conditions of heterogeneous terrain, fuels, and weather. The modeling approach uses an implementation of Huygens' principle of wave propagation for simulating the growth of a fire front. FARSITE requires the support of a GIS system, to generate and provide spatial data themes containing fuels, vegetation and topography.

The FARSITE software was initially developed for management support of prescribed natural fires (PNFs), now called fire use. The model was intended for both planning and operational phases. Among the many potential uses for fire growth simulations, the most relevant to FARSITE are short and long term projections of active and potential fire use fires. The Microsoft Windows interface offers flexibility for teaching in a classroom or field prediction of fire growth. Fire growth and behavior scenarios can be developed relatively quickly using short term weather forecasts or long term weather projections (ideally based on historic records). At last, different kinds of fire behavior can be considered.

FARSITE simulator is based on the BEHAVE [14] fire behavior prediction system. The FARSITE model incorporates five sub-models of fire behavior: surface fire, crown fire spread, fire acceleration, fuel moisture, and spotting from torching trees. All fire behavior calculations apply to the perimeter of a fire, which is the most important part of the investigation of the wildfire propagation phenomenon. Spatial data on fuels and topography required for these calculations are obtained from gridded maps from GIS information, while weather is obtained from data streams that discern time-dependent changes in wind speed, wind direction, temperature, and humidity.

Realistic predictions of fire growth ultimately depend on the consistency and accuracy of the input data layers needed to execute spatially explicit fire behavior models. FARSITE supports 2D and 3D graphical interface. It requires eight data layers for surface and crown fire simulations. These data layers must be both precise and consistent for all lands and ecosystems across the analysis area. More importantly, the layers must be congruent with all other GIS layers.

Comprehensive development of these input data layers requires a high level of expertise in GIS methods, fire and fuel dynamics, field ecology, and advanced computer technology.

So the FARSITE model, which is available for free to anyone both for use and for further development (open source), requires fuels layers that are quite costly and difficult to build. Unfortunately, most fire and land managers do not have the fuels maps, or even base maps from which they could create the fuels maps, needed to run the FARSITE model for their area. Most existing vegetation layers and databases do not quantify fuels information to the level of detail or resolution needed by FARSITE. Moreover, some attempts to create FARSITE layers from existing maps have failed because of inexperience with fuels and vegetation modeling and mapping in the context of fire behavior.

At last, it must be underlined that, FARSITE has been selected by many federal land management agencies as the best model for predicting fire growth. Besides, according to Sullivan's review paper [4], the two models found to best simulate the historical fires were FARSITE and Prometheus.

3. FARSITE: In-Depth Analysis

As mentioned in the last section, FARSITE is considered to be the most precise fire propagation simulation model by many researchers and even governments around the world. Based on this, in this section we present in depth and evaluate the simulator, which can be used for teaching in a university class.

At first, the landscape information (fuel model, slope, aspect, elevation, canopy cover, tree height, crown base height, crown bulk density, duff loading and coarse woody) is loaded, and right after the project is configured loading weather, wind, moisture and custom fuel models' parameters. Besides, there can be included vector files, corresponding to roads/highways, streams, barriers (e.g. firewalls), and generally everything that can prevent the spread of the fire. All the above information is drawn on a map, like the one given on figure 5.

The simulation starts and there can be illustrated several graphs, tables and maps, regarding fire area, fire perimeter, fire characteristic chart, post frontal combustion, fire numbers, environmental maps and combustion maps. During the simulation, one can observe the fire perimeter as it moves, as well as all the above tables and graphs. These are illustrated in figures 6 and 7. The tables' data can be exported to files, while graphs can be exported to bitmap files. Besides, queries can be performed for a specific spot on the map. The results of an example of such a query are illustrated in figure 8, indicating landscape information, as well as fire data information. Finally, the simulation ends, and the map of the final damage of the landscape is shown in figure 9.

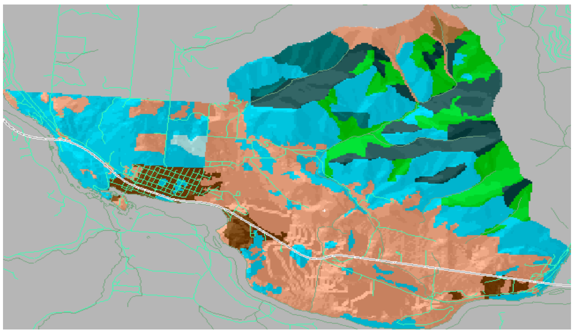

Fig. 5. Example of a landscape

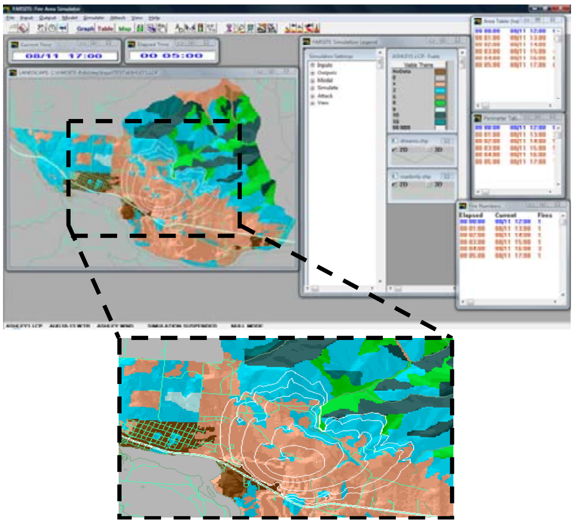

Fig. 6. FARSITE simulation as it runs–table results

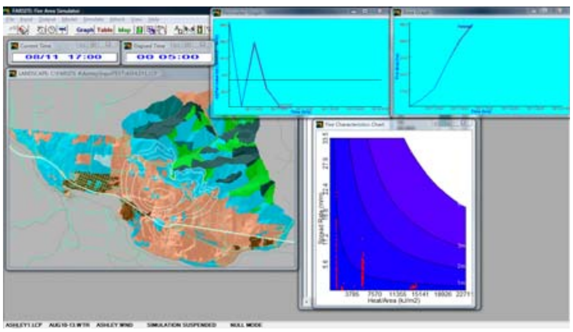

Fig. 7. FARSITE simulation as it runs–graph results

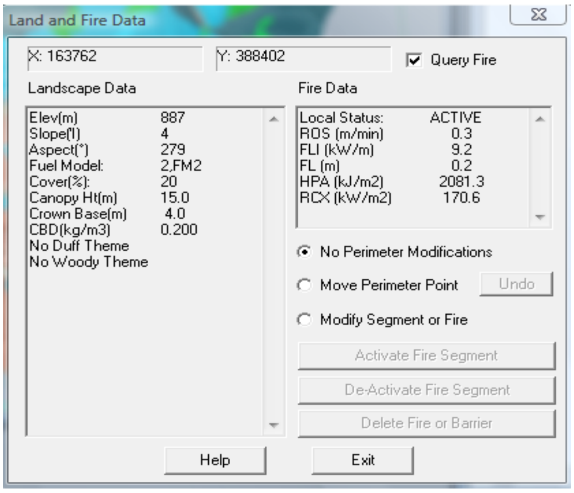

Fig. 8. Land and fire data query of specific coordinates

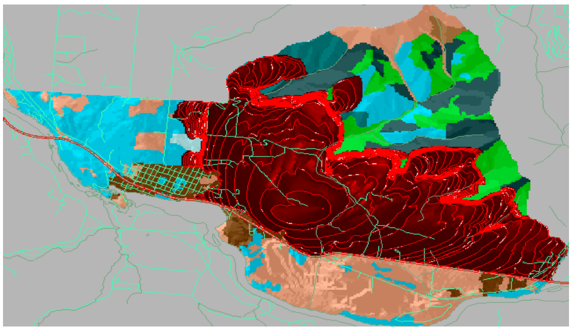

Fig. 9. End of simulation – illustration of the final damage of the landscape

Concluding, it should be mentioned that all graphs and tables presented in figures 6 and 7 alter as the simulation runs. Furthermore, figure 8 drives to some details regarding to specific coordinates of the landscape. Here it should be paid attention especially on the perimeter of the fire (the fire front) and how the several coordinates of it behave completely different, depending on the landscape information. Finally, from figure 9 it can be observed, among others, that in the southern part of the landscape the fire spreading is stopped by the presence of the barrier (this could be a highway or a firewall as mentioned above) that exist there. This fact also shows that if this barrier did not exist, then it should be built there to prevent more damage southern of the barrier.

As mentioned above, FARSITE can illustrate the results of its simulation in a 3D graphical interface. An example of this can be seen in figure 10.

Unfortunately, the FARSITE simulation model is not going to be upgraded anymore by the developers of the tool. The last version was released in May, 2008. Our intention is to make improvements to the source code of the model, and to make it applicable to our neighbor suburban forest, in Thessaloniki, Greece, at first, and to introduce the simulator as a lab lecture in our university.

FARSITE source code can be moderated to make the software able to import real-time weather conditions information, regarding temperature, wind, moisture, etc. In FARSITE the ignition of a fire is set manually. In the future, the exact place of the ignition of a fire can be pointed by an alarm given by a sensor, operating in a sensor network.

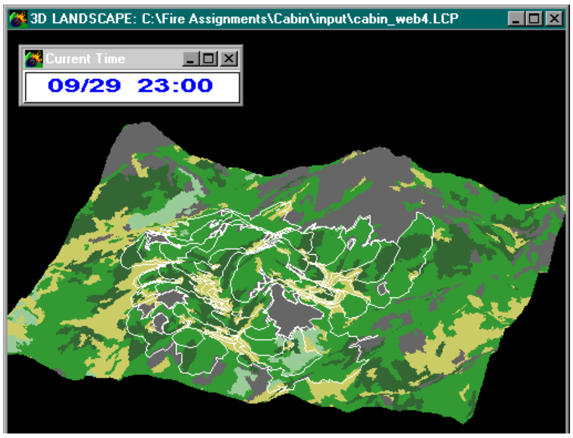

Fig. 10. 3D graphical interface output

4. Conclusion

In this paper, a review on wildfire simulation models has been presented. Before that, a brief analysis of wildfire modeling has also been made. Twenty-three simulators were found in the literature and the most significant are presented here. The basic parameters involved for the comparison of the simulators were mainly focused to the mathematical principles used, the input and the output data, the programming language, the last software release and if the project is still running, and whether the software is free for evaluation and development or not.

At last, FARSITE simulator was investigated in depth. The reason that FARSITE was selected to examine further, is that FARSITE is considered to be the most precise fire propagation simulation model by many researchers around the world. Besides, FARSITE has been selected by many federal land management agencies as the best model for predicting fire growth. FARSITE simulator model appears to be a very useful and user friendly tool, that can be used for teaching in a university lab.

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