3D WILDFIRE SIMULATION SYSTEM

Kıvanc Köse[a], Nikos Grammalidis[b], E. Erdal Yılmaz[c] and Enis Cetin[a]

[a] Department of Electrical and Electronics Engineering, Bilkent University,
[b] Informatics and Telematics Institute, Centre for Research and Technology Hellas, 1st km Thermi-Panorama road,
57001 Thessaloniki, Greece - ngramm@iti.gr
[c] Informatics Institute, METU

Commission VIII, WG VIII/11

ABSTRACT:

The increase in the number of forest fires in the last few years has forced governments to take precautions. Besides prevention, early intervention is also very important in fire fighting. If the fire-fighters know where the fire will be in some time, it would be easier for them to stop the fire. Therefore a big need for simulating the fire behaviour exists. In this paper we are proposing a system which can simulate the propagation of fire in time. Also this system can visualize the propagation of fire in any 3D-GIS environment that accepts KMZ as a file format. Besides, the system supports the visualization of a large number of output data from the simulations, according to the user needs. This facilitates fire planning by fire-fighters. 3D visualization at 3D screens is also supported. Therefore, a better understanding of the terrain can be obtained.

1. INTRODUCTION

In the last few years with the increase in the global warming, the world climate is changing. Two of the several main reasons in the global warming are the hole in the ozone layer and the destruction of the vegetation. These two issues invoke each other, thus consisting a vicious cycle. Due to the hole in the ozone layer the climates are changing and the due to the climate changes the vegetation is being destroyed. One of the main causes of destruction in recent years is wildfires. The increase in the seasonal temperatures also increased the number of self-ignited wildfires in mostly forest areas. Urged by the dry winds, and dry vegetation, some of these fires became disasters. Early detection is a very important issue for efficient fire intervention. It is much easier to cope with wildfires when they are local. Shorter the time between the ignition and the detection of fire, it is easier to extinguish it. While planning the deployment of fire fighters and equipment, estimation of the propagation of fire is very advantageous.

Parallel to the developments in computer sciences and electronics, the current trend is the development of automatic systems to cope with the problems mentioned above. Traditionally, governments hire people to monitor the potential fire regions. Governments construct observation posts at relatively high areas around the fire regions and place human observers at these posts. However by human observation alone, it is impossible to monitor the vast forest areas continuously. Hence, there is a significant need for automatic fire detection systems. The level of maturity of the existing solutions is relatively low. Therefore fire detection and propagation prediction is an open research issue. Several European countries are conducting research on these issues.

Turkey and Greece are two of these European countries which have significant interest in this research since several big forest fire incidents occurred especially during the last few years. An automatic fire and smoke detection algorithm was proposed in (Toreyin 2006,Toreyin 2005). A new camera-based fire and smoke detection system has been developed based on these

algorithms. The developed system is installed to the already existing fire posts in the forests of Turkey. Thus, the potential fire areas are currently monitored 24/7. The aforementioned system can detect the fire within a few seconds after its ignition. Additionally the coordinates of the fire ignition can be obtained through the system.

Another project called FIREMENTOR (Firementor,2008), which is a research project supported by the Greek government, is recently completed. It is focused on the provision of services for decisions and operational support in forest fire suppression. Self organizing fire sensor networks are used in FIREMENTOR. These sensor networks can be used for various applications like creating fire suppression scenarios, solving operational logistics problems and/or simulating and getting prepared for extreme operational situations. The system locates the ignition points and sends information about the propagation of fire to the server. By this way the deployment of the tactical forest fire suppression services is supported. A neural-network based system is used for the calculation of the propagation.

A multidisciplinary system is proposed in (Keramitsoglou, 2004). The proposed system provides rational and quantitative information based on the site-specific circumstances and supports decision makers during large-scale fire incidents. Near real-time satellite monitoring and satellite remote sensing, GIS are some of the technologies used in the systems architecture. The system can cope with multiple fire ignitions. Decisions regarding deployment of fire equipment and personnel can be done through this system.

Both of the systems were installed at Penteli Mountain near Athens, where a large fire took place in 2007. This fire demonstrated that many issues about early fire detection and prevention still remained unsolved. Especially the validation of the accuracy of the current fire propagation models is a big problem. Data from real forest fires are the main sources for this information. However in these cases the effect of external factors such as changes in the wind speed, human intervention, etc. on the model can not be accurately estimated.

Detecting the starting position of a fire is only the first step in fire fighting. After detecting a wildfire, the main focus should be the estimation of the propagation direction and speed. If the model of the vegetation and other important parameters like wind speed, slope, aspect of the ground surface, etc. are known, the propagation of the fire can be estimated (Rothermel 1972, Rothermel, 1983). Pioneered by (Rothermel 1972, Rothermel, 1983), several fire propagation models and software have been developed. However, only some of those systems allow the user to visualize the fire propagation on a Geographic Information System (GIS) environment.

The main motivation of this work is developing a fire propagation simulator which can visualize the propagation of fire in 3D. The system described in (Toreyin 2006,Toreyin 2005) is used for the detection of the ignition coordinates. Multiple detections (ignition points) are also supported. The heading direction and the timeline of fire can be calculated using the proposed algorithm. Google Earth[TM] is used as the 3D visualization environment. The 3D visualization gives a more realistic and easy to interpret view of fire propagation. Google Earth[TM] also allows the user to easily visualize any type of information needed. Fire equipment deployment can easily be done using Google Earth[TM]. The 3D visualization capability of Google Earth[TM] gives the user a very good intuition about the terrain. Therefore, the way of approaching the fire can be quickly decided.

The rest of this paper is organized as follows. In Section 2 the fire propagation simulator and its parameters are explained. In Section 3, the proposed calculation of fire propagation is described in detail. The visualization of the propagation data and associated information is provided in Section 4. Also some sample visualizations are illustrated in this section. In Section 5, conclusions are drawn and some future extensions of this work are discussed.

2. WILDFIRE SIMULATION LIBRARIES

Early intervention is a very important issue in wildfires. If the propagation of fire can be known beforehand, the deployment of the fire fighters and the equipment can be made effectively. Several research efforts are focused on this issue. In (Rothermel, 1972), fundamentals of wildfire behaviour are given and many issues like the effect of the fuel type, outside effects like wind humidity etc. are discussed. Furthermore, the issue of how to develop new fuel models is briefly discussed. Moreover definitions of some fundamental parameters like, heat of combustion, extinction time, spread coefficients etc. are provided. Referencing to (Rothermel, 1972) several fire propagation estimation algorithms like (Andrews, 1986, fireLib, 2008) are developed.

In this work we are using fireLib (fireLib, 2008) library as a basis. Using the functions defined in this library and some extensions of these functions, the proposed algorithm can calculate the propagation of the fire in 2D. fireLib uses the algorithms defined in BEHAVE fire model. BEHAVE (Andrews, 1986) was developed by the U.S. Department of Agriculture Forest Service in mid 80's and consists a very popular tool for predicting forest fire propagation. In the following we will briefly discuss the parameters used by fireLib and BEHAVE libraries. These parameters are used either directly or after modifications. For instance, specific modifications are required to support dynamically changing, with time, input parameters (e.g. wind, fuel type) and/or to support visualization of dynamically changing variables (e.g. flame length).

2.1 Fuel Model

In order for the propagation model to be efficient, forest fuels must be described in a particular way, in which the fuel characteristics are represented by certain average values. The set of these representative values is called a ``fuel model''. A drawback of the fireLib library is that it has only 13 default fuel models (Andrews, 1986). These fuel models are suitable for describing the vegetations of USA (fireLib, 2008), but may not be enough to describe the fuel model of an arbitrary location in the world. The main aim should be the development of site specific forest models and the estimation of their parameters. Furthermore methods of data accumulation using specialized maps, satellite imagery, databases of forest authorities, etc. should be defined.

Various researchers have developed such models for some of the most common fuel types in Greece and Turkey. In (Dimitrakopoulos, 1999), a small number of representative fuel models are defined for Greek forests, using statistical methods. Furthermore a simple methodology for the development of such fuel models is presented in (Xanthopoulos, 2002). The proposed method is based on biomass estimation, specifically that of shrubs, using regression equations. For creating a new fuel model, some properties of the vegetation and the environment like; depth of the fuel bed, dead fuel extinction moisture content, fuel particle load, surface area-to-volume ratio of the particle, etc. should be investigated. With the help of the governmental forestry organizations those information can be gathered. This gathered information will then be coupled with the GIS information. So the simulator can have an access to the specific fuel models for each map location.

Another way of defining fuel models is by using data from past fires. Directorates of Forestry both in Turkey and Greece are collecting GPS data from fire sites during the fires. They also have the data of the propagation of fire in time. These GPS data can be used in the simulations. By using iterative non-linear optimization techniques, the fuel parameters in the defined fuel models can be estimated by comparing the real life measurements with the simulation results. The optimal fuel model for a specific area is the one for which the error between the simulations and propagation measurements is minimized.

A future goal of this work will be the development of suitable fuel models for Turkey, Greece and the integration of these models within the proposed algorithm.

2.2 Environmental Parameters and Terrain

Besides the fuel parameters, environmental conditions are very important in the determination of the fire propagation. Especially the wind condition, humidity of the weather, slope and aspect of the terrain and humidity of the environment affects the fire propagation extensively. Some of this information can be obtained in near real-time but some of them should be estimated. Especially the estimation of the local humidity and wind speed is critical. The general weather information can be collected from local or global sources. However, the resolution of the wind direction and speed information may not be enough because weather sources mainly gives information about global winds. This information is mostly valid for flat and open areas. However, it is difficult to estimate the wind speed in a forest area consisting of valleys and hills, especially during a fire situation. The wind speed may not be uniform throughout these regions. Placing measurement devices to the observation posts, and using the accumulated data in these parameters can solve this problem to some extent. In the future we are planning to develop a new module for estimating the local wind direction around the fire. Videos

recorded by the fire detection system will be used for this purpose. By tracking the smoke and examining its scattering, the direction and the speed of the local winds will be more accurately calculated.

Wind is the most important factor that affects the propagation of the fire. Particularly in the absence of slope, fire propagates more rapidly towards the direction of the wind. Humidity is the second most important factor affecting fire propagation. Humidity of the environment has an impact on the humidity of the fuel, hence it affects its flammability and consequently the fire spread rate. Humidity of the environment depends both on the weather at the time of the fire and the former weather. If the weather was humid or rainy within the last few days, the fuel will be wet, thus which decreases the flammability of the fuel, and slows down the fire propagation.

Besides the weather conditions, terrain is another very important parameter for propagation simulation. Slope and aspect of the area affect the propagation speed and direction significantly. Fire propagates faster in the uphill and slowly in downhill directions. Aspect determines the wind terrain interaction. If the slope is facing to the wind direction the effect of the wind on the fire increases.

3. PROPAGATION CALCULATION BASED ON FIRELIB

Given the parameters above, the simulator can calculate the propagation of the fire on a landscape with varying conditions. fireLib divides the area of interest into cells. Each of the cells can have its respective fuel type, aspect, slope, etc. However, these parameters for each cell are assumed to be constant with respect to time. When a cell is ignited, the calculation of the ignition times for its neighbouring cells is performed. The propagation of fire from one cell to another depends on the ignitability of the cell, which is done only once per cell. This calculation yields an ignition time instant as well as an estimated flame length. However as the time increases and fire propagates further, some of the parameters in some cells may change (e.g. wind, moisture, fuel type). This issue is not taken into account in fireLib model. To cope with this problem, we take into account the dynamically changing parameter values within a recursive computation of the ignition times. Flame length is calculated once when the cell is ignited. To have a more realistic visualization we scale the flame length with a function that is decaying in time after some maximum. So in the visualization part, the flame length reaches to a maximum at some time $(t_{IGNITION} + t_{DURATION})/2$ and starts to decay afterwards. A future goal is to introduce accurate and realistic models for the dynamic changes of BEHAVE fuel and moisture parameters with respect to time, after a cell has been ignited.

3.1 Calculation of Surface Parameters

The slope and aspect of a terrain is not directly available in a GIS environment. Therefore, using the heights and coordinate values of points on the surface, these parameters can be obtained. Many techniques are available for the estimation of slope and angle from a Digital Terrain Model (DTM) (Cadell, 2002). We have used Horn's method (Horn, 1981), due to its reduced memory and computational requirements. Specifically, the slope and aspect are calculated using a *3x3* kernel (Figure 1), which covers the centre cell and its 8-neighbours.

h_{11}	h_{12}	h_{13}
h_{21}	h_{22}	h_{23}
h_{31}	h_{32}	h_{33}

Figure 1: The 3x3 kernel of cell height values, each corresponding to the elevation *h* at its center point.

From this kernel we calculate the north-south and east-west gradients as:

$$dEW/dz = [(h_{13} + 2h_{23} + h_{33}) - (h_{31} + 2h_{21} + h_{11})]/(8dx) \tag{1}$$

$$dNS/dz = [(h_{11} + 2h_{12} + h_{13}) - (h_{31} + 2h_{32} + h_{33})]/(8dy) \tag{2}$$

where *dx* is the East-to-West cell width and *dy* is the North-to-South cell height. Using the gradient formulas (1) and (2) the required aspect and slope values can be estimated as;

$$Slope = \sqrt{(\frac{dEW}{dz})^2 + (\frac{dNS}{dz})^2} \tag{3}$$

$$Aspect = \tan^{-1}(\frac{dEW/dz}{dNS/dz}) \tag{4}$$

The size of high-resolution SRTM data for large areas (e.g. an entire country) may become huge. Therefore storing all these data in each computer, where this program is installed, is not efficient. Instead, the application may be used more efficiently as a web service. In this way, height information data can be stored on a server and then only a small amount of data that are necessary to calculate a specific fire simulation, are transmitted to the client.

For test purposes we prepared a single DTM file, which covers the Aegean and the Mediterranean regions. While preparing the DTM file we used downloadable, free-use Shuttle Radar Topography Mission (SRTM) data, with 3 seconds intervals. The slope and the height information of any point can be obtained using this DTM file and its geographic coordinates (longitude and latitude) of each cell. Using this approach, we can calculate the fire propagation on any varying terrain.

4. VISUALIZATION

The second important step of the proposed system is the visualization of the calculated propagation data on a 3D-GIS environment. The fire propagation software in the literature yield a 2D view (mostly a top view) of the fire-site which may not provide a clear view of the situation to the persons responsible for the deployment of fire-fighting forces. Our aim is to visualize this raw propagation data on a more user-friendly 3D-GIS environment. For this purpose Google Earth[TM] is used in the proposed system. The main reasons of choosing Google Earth[TM] is because it is public available and widely used by experts and non-experts. Also it allows the creation of impressive 3-D animations of the fire propagation, in addition to the static view.

Moreover, due to its layered design, it provides the developer (and the user) enhanced flexibility to visualize various types of additional information on the map. For instance, the timeline of the propagation can be colour-coded and displayed. Positions of the deployed equipment, observation posts, fire-fighting units etc. can also be visualized on the map. An example view of the

colour-coded propagation visualization can be seen in Figure 2. The red coloured cells represent the areas which will burn first, and the cells with colour blue or its tones represent the cells that will ignite later. On the top of this colour-coding layer, another independent layer of time stamps may be placed (Figure 3). These time stamps show the estimated ignition time of each cell.

Another layer is the flame length layer. Especially in the animations of fire propagation, the flame length layer gives visually interesting results. With the dynamic calculations described in Section 3, the flame length changes in time so more realistic animations can be created. Another possible layer can be the roads, rivers, and fountains etc., which also play a crucial role to finalize the fire-fighting plan. All these layers are independent from each other; therefore the user can visualize all of them at once or chose the one he/she wants. Using these functionalities of the proposed approach, fire-fighters can more easily plan their movements and actions to confront the fire.
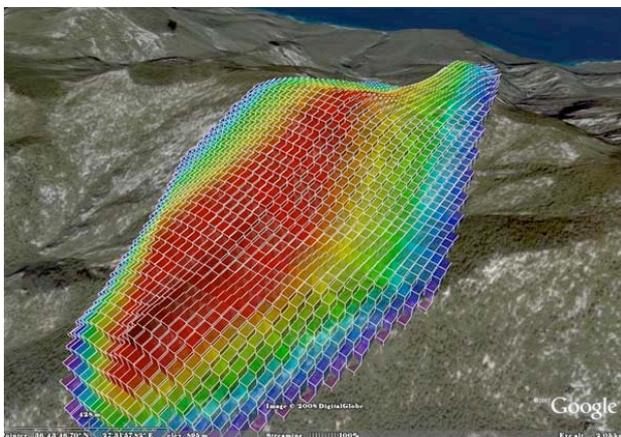

Figure 2: Ignition times using colour coding: red and its tones show the areas which will burn first, while blue and its tones show the areas which will burn later.

Figure 3: Time information of fire visualized with flames. The time information can be reached by clicking on the flame on the respective area

Google Earth^{TM} gives the availability of tilting and panning the view, thus allowing user interaction and enhancing the 3D feeling of the visualization (Figure 2). By this way a more realistic visualization of the topographical information of the terrain can achieved. The user can view the fire area from any angle and a more efficient fire deployment can be achieved.

Another advantage of Google Earth^{TM} is that it can be visualized in 3D using different types of 3D displays (Tridef, 2008). We have demonstrated several test fires on autostereoscopic displays, such as Sharp Actius AL3DU^{TM}. As a result, very realistic 3D visualization is obtained (Figure 4). The 3D visualization can be both static (Figure 5) or dynamic (animations, as in Figure 6). Besides the terrain information, all the other layers can also be visualized in 3D. Together with the tilting and panning, the 3D view makes the user feel, as if he/she is at the fire area.

For using realistic flame lengths in these visualizations, new software modules are developed. The time specific flame length maps will then be imported, visualized and/or used to create animations showing the spread of a fire within the Google Earth^{TM} platform. For this reason, KML/KMZ files are generated. The use of KML/KMZ file formats will also allow us to visualize results on several other popular GIS platforms as well. Integrating all the mentioned components above and the video based smoke detection system mentioned in (Toreyin, 2006), a complete wildfire detection and simulation system with a 3D visualization will be created.

Figure 4: Flame length information is also shown in frames of propagation animation. This type of animation can be visualized in 3D on Sharp Actius^{TM} autostereoscopic laptop computer.

Recently, we have also designed and we are currently testing a Web interface, based on PHP, that allows a user to specify all necessary parameters related to the fire modelling procedure (e.g. number and dimension of cells, geographic coordinates of the ignition point, etc.), as well as the desired type of visualization (ignition time, dynamic animation of flame length, etc). By pressing a specific button, the fire simulation can executed in the server and the resulting KML file is provided to the user, which can be visualized on Google Earth^{TM} or stored for future reference.

5. CONCLUSIONS AND FUTURE WORK

The proposed system can produce realistic simulations using the geographical information at a given region. The results of these simulations are statically or dynamically visualized on Google Earth^{TM}. Features of Google Earth^{TM} eg. zooming, tilting, panning, offer the user a better view of the site and the fire progress. Additional logistics information can be placed on Google Earth^{TM}, so that fire site planning can also be done using our software. Moreover if the user has a PC with support for an autostereoscopic display, he/she can visualize everything in 3D. This is a totally new approach in fire propagation simulation.

There are some issues that we should deal with in the future. The most important one is the derivation of the fuel models of Turkey and Greece. For now we simply use the most appropriate model among the 13 already defined models in fireLib. However, we are planning to derive more accurate forest models of Turkey and Greece. Another future issue is to obtain the wind information in real time. Wind information obtained from meteorology or devices on the fire posts can not be precise enough and offers limited resolution for our simulations. Therefore, we are planning to develop an algorithm to estimate wind speed from the videos of the fire sites.

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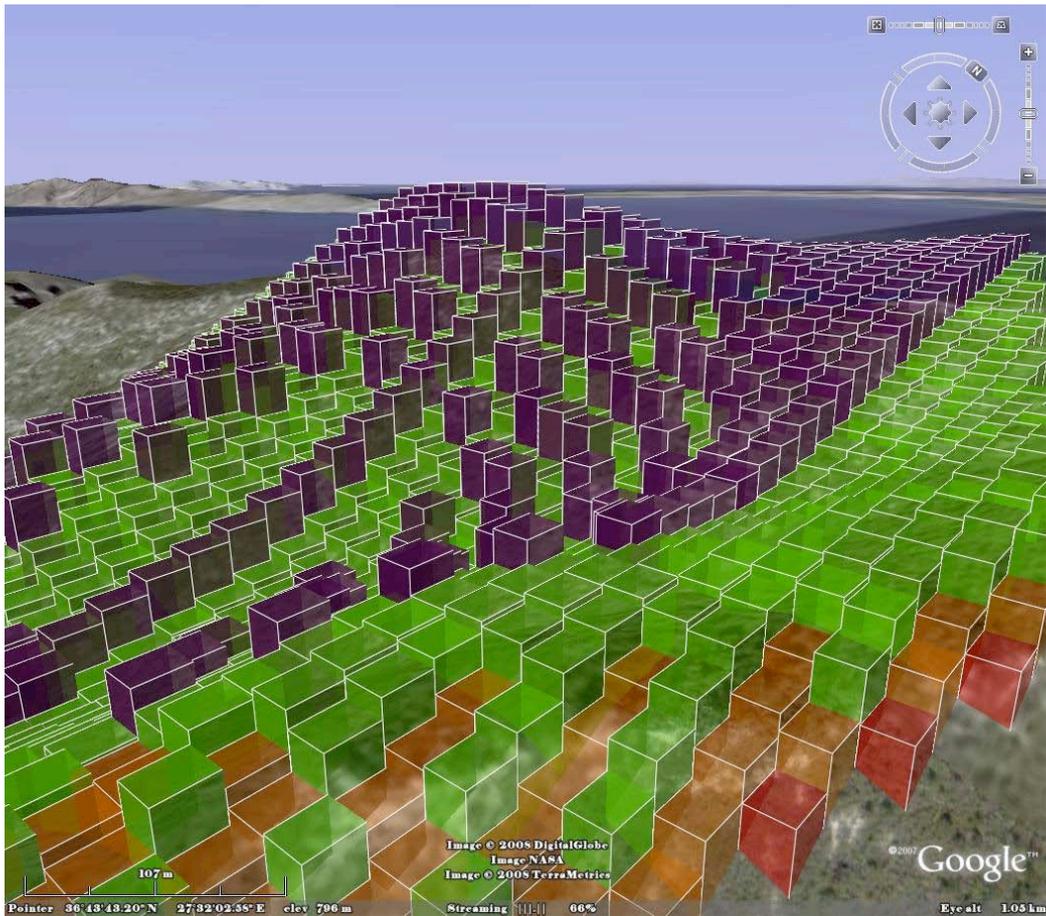
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Figure 5: Flame length information is also shown in frames of propagation animation. This type of animation can be visualized in 3D on Sharp Actius[TM] autostereoscopic notebook..
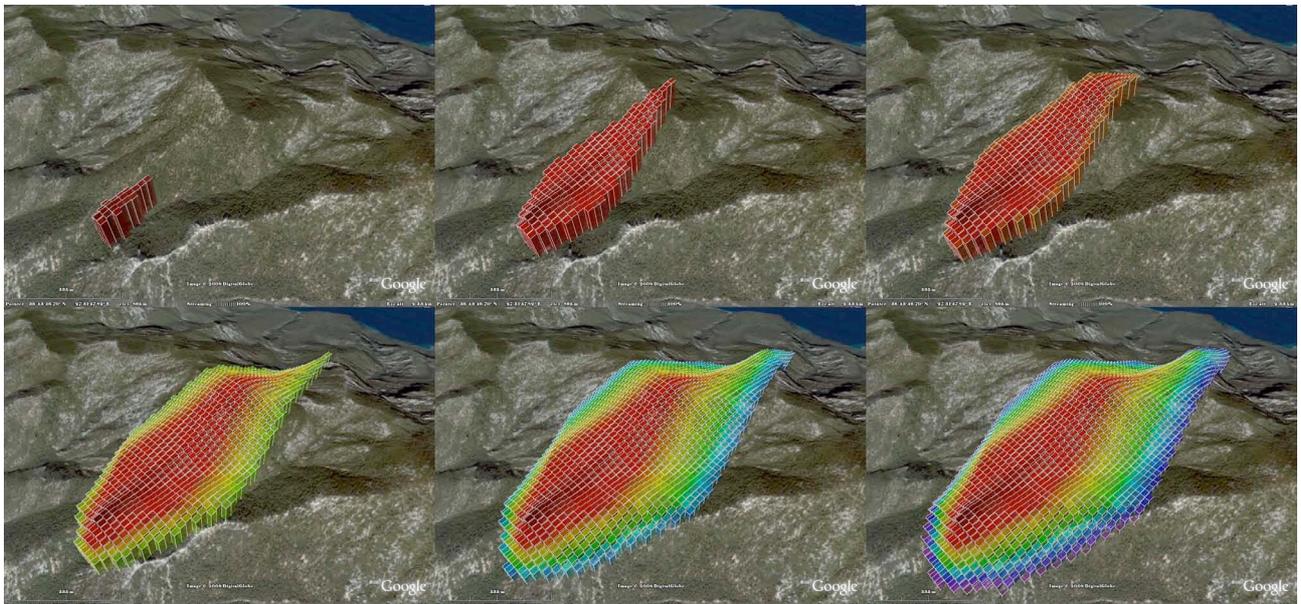

Figure 6: Animation of fire propagation is composed of several frames showing the propagation at different times.