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26. Application of GIS Tools in Wildland Fire Modeling for South Bulgarian Test Cases

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Abstract: This article will present a summary of a work that has been done in a period of several years. The article illustrates how all available data and ICT tools which were available during this period in Bulgaria were used in wildland fire propagation modeling. The described test case is in south-central part of Bulgaria where the most fire-prone non-urban areas of the republic are. The data availability and the used tools to collect the missing pieces for simulations are described and visualized with pictures from the test simulations.
Keywords: Forest fires, GIS tools, Environmental modeling, ICT tools, Fire propagation.

INTRODUCTION

The studies of wildland fire propagation have basic principles and mechanisms of combustion processes, which are the fire fundamentals. Fire behavior is what a fire does. i. e the dynamics of the fire spread. An understanding of the fundamentals of wildland fire is important for some very practical reasons. The combustion process can be manipulated to some extent: Retardants can be applied to affect the combustion process: fuel arrangement can be altered for hazard reduction; and appropriate environmental conditions can be selected for prescribed fires to reduce smoke impacts, achieve desired fuel reduction, and still retain control of the fire. The need to understand wildland fire fundamentals is even more pressing nowadays than it was in the past. In earlier times the focus was on describing the aspects of fire that are important to suppression efforts. That continues to be a high priority. In addition, there is now increasing emphasis on characterizing fire for its effect on vegetation and for the smoke it produces.

The basis for fire modeling is the Rothermel model for the behavior of surface fires (Rothermel, 1972). It calculates for any given point local intensity and spread parameters for the surface fire. Inputs for the model are a two-dimensional wind field, terrain parameters, fuel moisture and a detailed description of the fuel bed. Based on the local behavior output by the Rothermel model and on a model for the local shape of fire spread, the propagation from a set of source locations can be simulated. The influence of barriers (streets, rivers, fuel breaks, etc.) is addressed with a probabilistic model based on the width of the barrier and the flame length. The spread simulation also allows the calculation of the flame length on the entire fire perimeter, which in turn is an important factor for the success of various types of fire suppression activities.

The mathematical models require descriptions of fuel properties as inputs to calculations of fire danger indices or fire behavior potential. The set of parameters describing the fuel characteristics have become known as fuel models and can be organized into four groups: grass, shrub, timber, and slash. Fuel models for fire danger rating have increased to forty while fire behavior predictions and applications have utilized the thirteen fuel models tabulated by (Rothermel, 1972) and (Scott-Burgan, 2005) creating an updated version of the first smaller set. Each fuel model is described by the fuel load and the ratio of surface area to volume for each size class; the depth of the fuel bed involved in the fire front; and fuel moisture, including that at which fire will not spread, called the moisture of extinction.

The fire models used nowadays by wildland fire managers are specified to distinct types of fire behavior. There are separate models for surface fires (Rothermel, 1972; Albini, 1976), crown fires, which have been theoretically investigated in great details by (Perminov, 2003; Van Wagner, 1993), spotting (Albini, 1979), and point-source fire acceleration (Cheney and Gould, 1997). This fire spread

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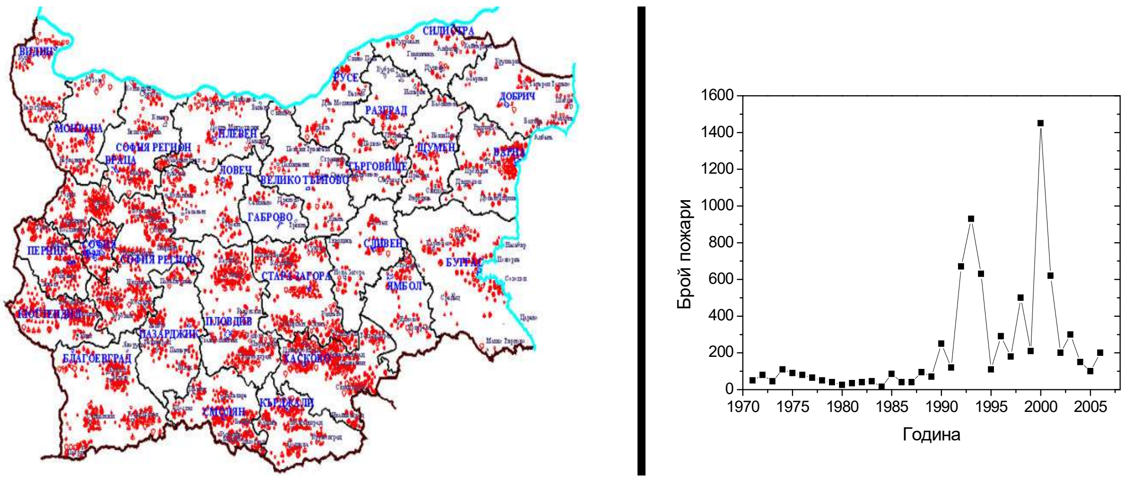
types are really abstractions of overall three-dimensional process describing unconfined combustion that links implicitly to the environment through heat and mass transfer cycle.

Not only fire behavior models have been developed in the past years. The way of predicting fire behavior has been transformed from nomograms to calculator, and then to computer based systems with Mobile and Desktop versions for field operations support.

The PC-based programs for fire behavior have been developed starting with FSPro fire spread probabilities; FARSITE fire area simulator; FlamMap fire mapping and analysis system and BehavePlus fire modeling system. In the last few years, very good results have been published for the Wildfire analyst system (Ramirez et al,, 2011). The last one is using the fire algorithms from the previous systems and is a collection of models that describe the fire spread in near real time.

The statistics of the EU countries for the last 30 years represent a significant increase of wildland fires. Although Bulgaria haven't been included in EU statistics to the end 2006, Bulgaria has done statistical analysis about forest fires on its territory in the period 1994-2006. There is data about the number of forest fires every year collected between 1971 – 2006 (web-site: official bulletin of Ministry of Forestry in Bulgaria) Figure 1. It is clearly seen from Fig. 1(b) that there is a considerable increase of the number of forest fires in Bulgaria after 1990 and especially in 1993 and 2000 when fire activity peaked and more than 1000 wildland fires devastated huge areas of forests in the lowlands as well as in the mountains. The number of fires and the average size of the fires have increased about 6 times in the recent years, however the total burned area and the percentage of vegetation burned during a year has increased dramatically - more than 30 times. Even though the number of wildfires is increasing and the consequences are not only of environmental, but also of economical and social significance, proper solution haven't been found. At present most of the countries suffering from wildfires are dealing with the disaster at the moment of its occurrence.



(a) (b)

Figure 1. (a) Bulgarian forest fires in the period 1994-2006, separated by regions;
(b) total number of the forest fires per year in Bulgaria between 1971 and 2006

Another statistics were done by the team in BAS using NASA hot spots free data sets for Bulgaria have given information about wildland fire occurred after the years of 2006 and how the burned areas and periods are distributed (figure 2). Very important information extracted from the NASA data sets was that the most vulnerable months during the year for wildland fires to occur are divided in two major time slots. The first one is in the range of the February – April months and the second covers the months from July until October (figure 3).
These statistics and all data which was collected further gave the basic push up on the BAS team to start developing the topic of wild land fire prediction by usage of ICT tools.

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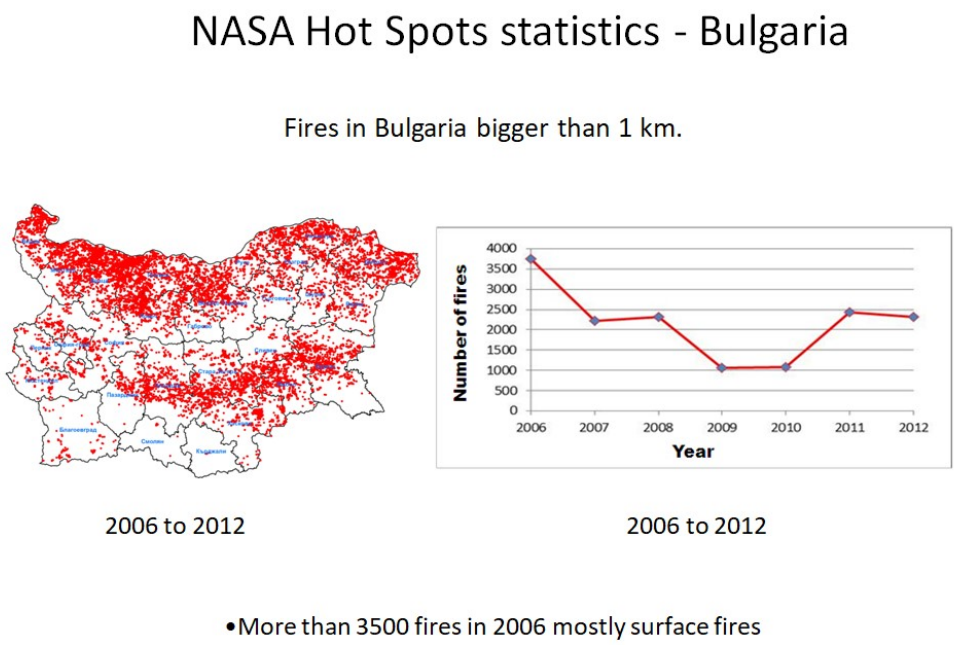

Figure 2. NASA hot spots statistics about burned areas in Bulgaria after the years of 2006

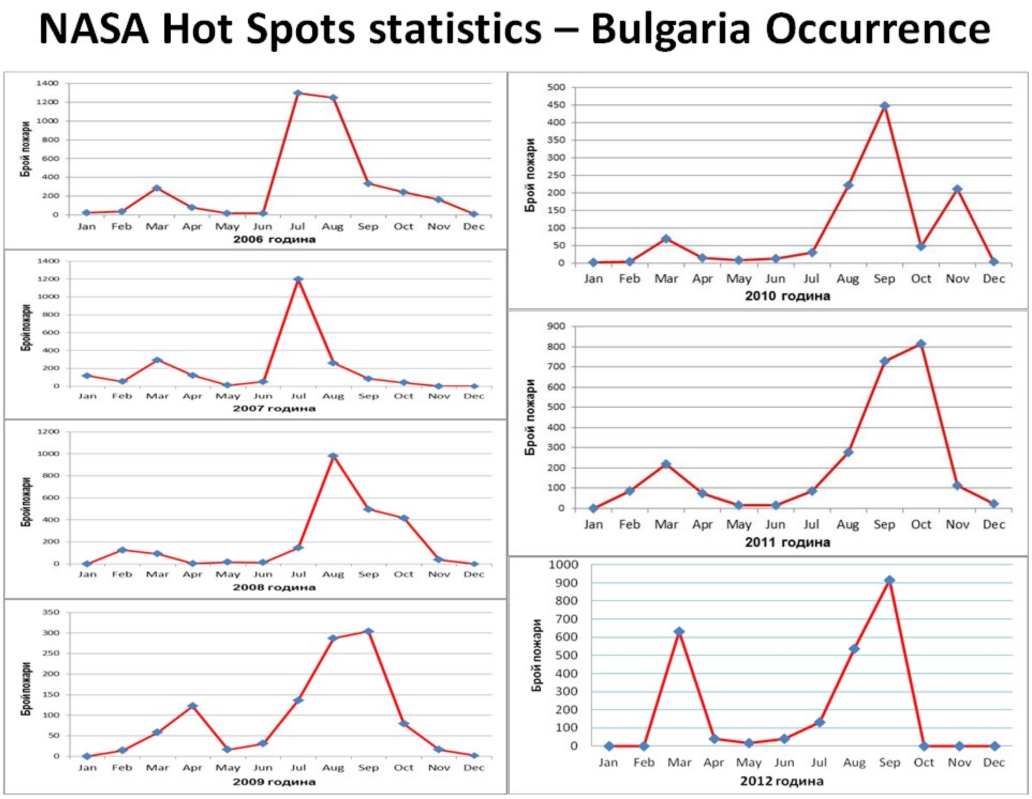

Figure 3. Time frame of months when are the most probable periods for wild land fires in Bulgaria

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MATERIALS AND METHODS

Worldwide research about wildland fire propagation has begun in the center led by Rothermel in Missoula Fire Laboratory in Rocky Mountains (Rothermel, 1972). In fact, Rothermel and his team in Missoula are considered as founders of the fire modeling research. The first working wildland fire behaviour model was created in 1972 and since then it has been improved several times. Every subsequent model's modifications included consideration of further parameters that could make the simulations obtained by the scientists more realistic and accurate.
In the early 80's of the last century, M. Grishin, professor at University of Tomsk, Russia, has worked on and developed a model (Grishin et al, 1983), which uses data about the burning material types in the taiga (mostly conifers) and takes into account that the main combustion intensity happens in the crown of trees.

Approximately at the same time attempts for wildland simulations were done in laboratories in Sydney, Australia. The Russian and Australian models did not become as popular as the US ones, because of some computational issues at that time, concerning PC power, data coverage, etc. Nowadays many laboratories are involved in wildland fire behavior propagation modeling. It is easier to find them in the affected zones, simply because this knowledge is saving time and efforts when it is working together with the incident commanders on the field.
The development of modern information and communication tools allows applications of cutting-edge technologies to solve problems related to the forest and field fires. Usage of these tools not only allows early detection of fires but also gives possibility for prediction of the dynamics related to fire spread of the fire line and the extent of the possible damages for the environment and citizen's property.
The main types of wildland fires described in the specialized literature are classified as follows:
type 1 - surface fires;
type 2 - crown fires;
type 3 - spotting fires as modified crown fires
type 4 - fire acceleration, when the terrain has steep slopes.

Bulgaria has mainly fires from types one and two and rarely fires from types three and four. The research on the wildland fire behavior modeling has not been developed in the past, which makes Bulgarian scientist beginners in the area of fire behavior simulations. In this paper we will describe how we calibrated data for FARSITE model by using GIS tools for preparation of the available data into the shape needed for of the model.
The data which we have collected was for the area of Zlatograd forestry department. All of which has been provided in paper maps, which we digitalized and in order to use them we found forestry database with description for each of the poligons and sub-poligons in the paper maps where our test fire shapes were.

Than in order to create canopy cover and fuels models for the FARSITE simulations we used point layer created for each of the fires, shape files for each burned area, the polygons of the forestry department database and the DEM, Aspect and Slope for the area of interest on the map. We had some ortophoto images for the territory of the test area fires so the possibility for us to determine canopy cover and fuel model by the comparison between the ortophotos and the forestry maps was used.

The Rothermel approach behind the surface fire spread used for the simulation results is presented by formula (1) and the method in FARSITE is based on it. Its representation is as follows:

$$R = \frac{Heat\ Source}{Heat\ Sink} = \frac{I_{xig} + \int_{-\infty}^{0} \left(\frac{\partial I_z}{\partial z} \right)_{Z_c} dx}{q_{be} Q_{ig}}, \qquad (1)$$

where:

R – is parameter for re spread or the so called ROS(quasi-steady Rate Of Spread),

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I_{xig} – is the horizontal spread of the heat absorbed by the burning materials evaporating their water content,

q_{be} – is the density of the burning materials which are heated until the re start,

Q_{ig} – is the absorbed energy by the burning materials while they are evaporating their water content,

$\frac{\partial I_Z}{\partial z}$ – is the gradient of vertical intensity in the plane, where the energy is released

The data we were working on was about fifteen wildfires that occurred in the period 2011 - 2012 within the Zlatograd forestry department. This data included vegetation type, area burned (in decares where 10 decares = 1 hectare), date, and start and end hours of the fire event. These wildfires burned in a variety of vegetation types and were more than likely started by humans to clear agricultural debris or prepare fields, based on the proximity to villages.

RESULTS AND DISCUSSIONS

In the framework of bilateral cooperation program between Greece and Bulgaria 2007-2013, our team was having the opportunity to work in the Zlatograd forestry department. The study area was the territorial state-owned forestry department in Zlatograd, which covers an area of 33,532 ha, where 31,856 ha are state forests. Most forests are in early to mid-seral successional stages, with only small amounts of mature to old forest. Standage is highly variable, ranging from 20 to 80 yrs; most stands range between 35 to 50 yrs with the average being 46 yrs. Average stem stock is 140 m3 ha-1. The average forest canopy cover is 81%.

In terms of climate, the region is part of the continental-Mediterranean climatic region, south-Bulgarian climatic sub-region, and East Rodopi mountain low climate region. The average annual temperature is 10.8ºC, with a maximum temperature in July of 20.6ºC and minimum temperature in January of -0.8ºC, indicating moderate summers and relatively mild winters. Extreme values of annual average maximum and minimum temperature are respectively 17.1ºC and 4.9ºC, the monthly maximum is in August (28.9ºC) and the average monthly minimum occurs in January (-3.9ºC). Average annual rainfall reaches 1000 mm. Maximum precipitation amounts for the period from April to October range from 10.0 mm for 5 min to 46.3 mm for 60 min and 59.7 mm for more than 60 min. The average annual relative humidity is 75% which is an indication of good growing conditions; maximum relative humidity values of 85% occur in November. However, approximately 13-15 days per year have relative humidity less than or equal to 30%, during which time wildfires may be of higher concern.

The data we were working on was about fifteen wildfires that occurred from 2011 to 2012 within the Zlatograd forestry department. Paper maps from the forestry department identified the ignition location and final fire shape; this data was digitized in a GIS which allowed each ignition point to be viewed with background orthophotos and the spatial Zlatograd vegetation classification showing pre-fire vegetation (Table 1).

After we collected and located the forest fires we did runs with BehavePlus point based prediction system in order to analyze fire growth and behavior for homogeneous vegetation with static weather data. We used standard fuel models developed for the US and we evaluated which fuel models were best able to produce estimates of fire behavior and growth in BehavePlus similar to those observed on each of the fifteen fires. Due to the paucity of available weather data in Bulgaria, we had to assume that weather recorded for the weather station closest to each particular fire is consistent with weather experienced on the wildfire. We estimated live herbaceous and live woody fuel moisture values based on the expected phenological stage for the time of year that the fire occurred. To estimate slope, we first used a 30 m resolution digital elevation model (DEM), then subsequently calculated the average slope for each fire using standard geospatial processing in ArcGIS (ESRI 2010). Burn period length for each fire was obtained from the Zlatograd forestry department data (Table 1).

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Table 1. Fire information provided by the Zlatograd Forestry Department for the period 2011-2012

Fire No.	Vegetation type	Burned area in decares	Date of occurrence	Hour of start	Hour of end
1	Durmast	3.0	25 March 2012	1330	1530
2	Beechwood	5.0	29 March 2012	1400	1800
3	Scotch pine	1.0	16 June 2012	1500	1700
4	Scotch pine	7.0	6Aug. 2012	1640	1950
5	Scotch pine	5.0	6 Aug. 2012	1710	2130
6	European black pine	4.0	27Aug. 2012	1200	1600
7	Scotch pine	3.0	5 Sept. 2012	1400	2030
8	Scotch pine	6.0	6 Sept. 2012	1400	1930
9	Scotch pine	2.0	6 Oct. 2012	1600	2320
10	Scotch pine	1.0	16 March 2011	1310	1400
11	Scotch pine	1.0	5 April 2011	1715	1900
12	Scotch pine	1.0	10 April 2011	1130	1530
13	Grassland	3.0	30 Aug. 2011	1400	1800
14	Scotch pine	4.0	12 Sept. 2011	1230	1900
15	Scotch pine	1.0	15 Sept. 2011	1600	1830

Based on initial BehavePlus results using standard fuel models, custom fuel models were developed for some vegetation types not well represented by the US fuel models. Custom fuel models were developed for native durmast oak and grass as well as one of the Scotch pine sites by modifying fuel loading parameters to better match local vegetation and reflect the lack of woody debris in the understory.

Following evaluation of fuel models with BehavePlus, we then performed analyses in FARSITE, a spatial fire growth system that integrates fire spread models with a suite of spatial data and tabular weather, wind and fuel moisture data to project fire growth and behavior across a landscape. We defined our test landscapes using a 500 m buffer zone around each of the fifteen Zlatograd fires.

Input for FARSITE consists of spatial topographic, vegetation, and fuels parameters compiled into a multi-layered "landscape file" format. Topographic data required to run FARSITE include elevation, slope, and aspect. Using the aforementioned 30 m DEM, we calculated an aspect layer, and then clipped elevation, aspect, and slope rasters to the extent of our fifteen test landscapes. Required vegetation data include fuel model and canopy cover. Fuel models within the 500 m buffered analysis area for each individual fire were assigned based on our BehavePlus analyses; fuel model assignments were tied to the dominant vegetation for each polygon based on the Zlatograd forestry department's vegetation data. Canopy cover values were visually estimated from orthophoto images and verified withstand data from the Zlatograd forestry department. Additional canopy variables (canopy base height, canopy bulk density, and canopy height) that may be included in the landscape file were omitted, as these variables are most important for calculating crown fire spread or the potential for a surface fire to transition to a crown fire. None of the fifteen fires analyzed experienced crown fire.

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Tabular weather and wind files for FARSITE were compiled using the weather and wind data on hourly records. Tabular fuel moisture files were created using the fine dead fuel moisture values calculated for the BehavePlus analyses for 1-hr time-lag fuels. The 10-hr fuel moisture value was estimated by adding 1% to the 1-hr fuel moisture and the 100-hr fuel moisture was generally calculated by adding 3% to the 1-hr fuel moisture. The live fuel moisture values previously estimated for BehavePlus analyses were used to populate live herbaceous and live woody moisture values.

All simulations performed in FARSITE used metric data for inputs and outputs. An adjustment value was not used to alter the rate of spread for standard fuel models, rather custom fuel models were created. Crown fire, embers from torching trees, and growth from spot fires were not enabled.

As an example of one of our successful FARSITE runs, we present the results from a single wildfire that burned in grassland vegetation, for which we developed custom fuel models. This fire occurred on August 30, 2011, starting at 1400 and ending around 1800, and burned a total area of 0.3 ha. We used the following input parameters to model this small grassland fire in FARSITE:

Fuel moisture values: 6% (1-hr), 7% (10-hr), 9% (100-hr), 45% (live herbaceous), and 75% (live woody);

Daily maximum temperatures: 17-21°C;

Daily minimum relative humidity: 24-50%;

Winds: generally from the west-southwest at 1-2 k h-1

The fire size as calculated using FARSITE was 0.5 ha, which seems reasonable considering the modeled size would not have included the suppression actions that most likely occurred given the close proximity of a village to this fire figure 4.

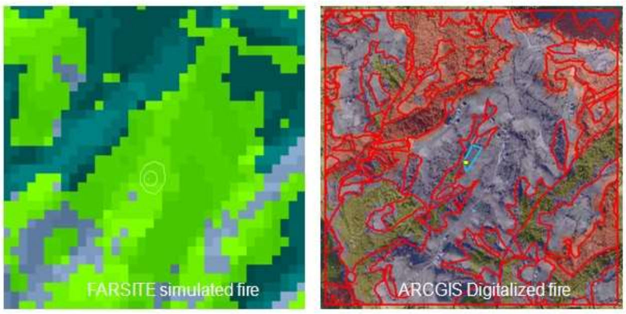

Figure 4. FARSITE run for a grassland fire, where size of the fire is very close to the real one, but the shape is different, because of wind information discrepancies

CONCLUSIONS

From this work, we managed to do first successful calibrations of US model and tools for an area where wildland fires occur on a regular basis. All estimated parameters and results are well documented and based on the desktop and mobile apps are to be launched for the use of the local firefighters and volunteer groups.

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REFERENCES

Albini F A., 1976. Estimating wildfire behavior and effects. USDA For. Serv. Gen. Tech. Rep. INT-30, Intermt. For. and Range Exp. Stn., Ogden, Utah, 92 p.

Albini F.A., 1979. Spot fire distance from burning trees - a predictive model. USDA For. Serv. Gen. Tech. Rep. INT-56.

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Cheney N.P. and Gould J.S., 1997. Letter to the editor: fire growth and acceleration. Intl. J. Wildl. Fire 7(1): pp.1-6.

Grishin A., Gruzin A., Zverev V., 1983. Mathematical modelling of the spreading of high-level forest fires. Soviet Physics Doklady, 28(4):328-330.

Ramírez J., Monedero S., Buckley D., "New approaches in fire simulations analysis with Wildfire Analyst". The 5th International Wildland Fire Conference Sun City, South Africa, 9–13 May 2011, pp. 1-15

Perminov V., 2003 Mathematical Modeling of Crown Forest Fires Initiation, Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics) 2667, pp. 549-557.

Rothermel, R. C., 1972 A mathematical model for predicting fire spread in wildland fuels. Research Paper INT-115. Ogden, UT: US Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, pp. 1-40

Scott J.H., Burgan R.E., 2005 Standard fire behavior fuel models: a comprehensive set for use with Rothermel's surface fire spread model. USDA Forest Service, Rocky Mountain Research Station General Technical Report RMRS-GTR-153. (Fort Collins, CO)

Van Wagner.C.E., 1993. Prediction of crown fire behavior in two stands of jack pine. Can. J. For. Res. 23:442-449.

*****, Official Bulleting of Ministry of Forestry in Bulgaria: Internet resources of the National Fire Safety and Civil Protection Service of Bulgaria– http://www.nspbzn.mvr.bg/Sprav_informacia/Statistika/gorski.htm

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