

Bulgarian fuel models developed for implementation in FARSITE simulations for test cases in Zlatograd area

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Abstract: As a key component of the cross-border project between Bulgaria and Greece known as OUTLAND, a team from the Bulgarian Academy of Sciences and Rocky Mountain Research Station started a collaborative project to identify and describe various fuel types for a test area in Bulgaria in order to model fire behavior for recent wildfires. Although there have been various efforts to map vegetation in Bulgaria, these datasets have not directly provided the types of data necessary to use the wildfire spread models. This project focuses on using available data sources for Bulgaria including paper maps displaying Bulgarian vegetation in 1991 (Bondev 1991), high resolution orthophotography from 2011, Corine Land Cover spatial data (<http://www.eea.europa.eu/data-and-maps>), and both paper and spatial vegetation maps from the local municipal forestry department. The objective of this paper is to describe a methodology that can be used in simulating wildfires for the Zlatograd region of Bulgaria. This methodology includes classifying the surface fuels using both custom fuel models and fuel models developed and commonly used in the United States (Anderson 1982; Scott and Burgan 2005), reformatting local weather data, and performing fire behavior simulations using the FARSITE fire area simulator for fifteen fires in the study area.

Additional Keywords: Zlatograd, OUTLAND project, Greece-Bulgaria cross-border program, FARSITE, fire behavior modeling, custom fuel models.

Introduction

In 2011, the Institute of Mathematics and Informatics of the Bulgarian Academy of Sciences (BAS), in cooperation with multiple consortium partners, received a grant from the European Union for a project titled “Open protocols and tools for the education and Training of voluntary organisations in the field of Civil Protection, against natural Disasters (forest fires) in Greece and Bulgaria”, known as the OUTLAND project (<http://www.outland-project.eu>). Consortium partners include: the municipality of Thermi as lead partner, the municipalities of Komotini and

Zlatograd, the management authority of the "Dadia-Lefkimi-Soufli Forest" national park, and the Centre for Research and Technology Hellas, Informatics & Telematics Institute.

The main objective of the OUTLAND project is the establishment of a framework for the vocational training and preparedness of volunteers who operate within the civil protection mechanisms in Greece and Bulgaria and are involved in the prevention of wildfires, as well as protection and rehabilitation of ecosystems affected by fire. The project focuses on the exchange of experiences and best practices, the production of multilingual training materials, and development of a joint understanding in the cross-border territory to improve safety and response efficiency of the volunteers.

OUTLAND's primary focus is to provide a permanent mechanism for the municipal authorities, where volunteer groups are established in both countries, to communicate and cooperate in cases of common disaster. The research and teaching procedures are based upon technical, economic, and procedural criteria to provide for adequate preparation of volunteer groups in institutional level programs. Educational materials developed as part of OUTLAND include instructions for using computer-based tools such as fire behavior prediction systems. Where necessary input data representing terrain, weather conditions, vegetation, and surface fuels exist or can be developed, these tools could be used to simulate past fire events for calibration purposes and actively burning fires for decision support. As part of our project we sought to create a fuels classification adapted to the Zlatograd test area and subsequently test existing fire behavior modeling tools developed in the United States to analyze the spread of past wildfires, neither of which has ever been done for the Zlatograd area or any Bulgarian municipal territory. If successful, this effort could be used to guide operational implementation of these computer-based decision support tools in the future.

Along with the basic educational materials developed for the volunteer groups, the team at BAS started collecting information for recent wildfires occurring between 2011-2012 within the Zlatograd municipal territory, including the towns of Zlatograd, Madan and Nedelino. The fifteen reported wildfires were fairly small, but caused the deaths of four volunteers in 2012. No statistical records are kept for such casualties and the only sources of information are from people who worked in the field during such incidents. We also considered that scenarios displaying possible movement of the fire front, especially as impacted by the effects of wind and topography, could be used as a training tool in educating local volunteers. BAS partnered with the USDA Forest Service's Fire Modeling Institute, part of the Rocky Mountain Research Station located at the Missoula Fire Sciences Laboratory in Missoula, Montana, to establish methods for analyzing fire behavior and fire growth using the FARSITE fire area simulator (Finney 2004) and the BehavePlus fire modeling system (Andrews 2007) for fifteen Zlatograd area wildfires.

Methods

Study area

The territorial state-owned forestry department in Zlatograd covers an area of 33,532 ha, of which 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. Stand age 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 10.8°C, with a maximum temperature in July of 20.6°C and minimum temperature in January of -0.8°C, indicating moderate summers and relatively mild winters. Extreme values of annual average maximum and minimum temperature are respectively 17.1°C and 4.9°C, the monthly maximum is in August (28.9°C) and the average monthly minimum occurs in January (-3.9°C). 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.

Fire Locations

Data for fifteen wildfires that occurred in 2011 to 2012 within the Zlatograd municipal territory were provided by 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 (table 1). 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. 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 (Figure 1).

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.	1600	1830

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



Figure 1a: Digitalized shapes from paper map



Figure 1b: Paper map sample

Data preparation and analysis

The first step in preparing data to run spatial fire behavior analyses was to determine suitable fuel models for fire locations in our Zlatograd test area. We did this using BehavePlus (Andrews 2007). BehavePlus is a point fire behavior prediction system that can be used to analyze fire growth and behavior for homogeneous vegetation with static weather data. Using a number of standard fuel models developed for the United States (Anderson 1982; Scott and Burgan 2005), 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.

In addition to fuel model, BehavePlus requires inputs for weather, fuel moisture, slope, and duration of the burning period. We obtained weather data for each fire from TV Met, a private company in Bulgaria, which provided the ability to calculate fine dead fuel moisture values (Rothermel 1983). 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 acquired a 30 m resolution digital elevation model (DEM) from the National Institute of Geophysics, Geodesy, and Geography in Bulgaria, 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).

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, as it is collected as firewood by the local population. The custom fuel model developed for grass has a much lower rate of spread and flame length than any of the standard grass fuel models.

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 (figure 2); this footprint comprised the extent of the spatial analysis for each individual wildfire.

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 with stand 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.

Tabular weather and wind files for FARSITE were compiled using the weather and wind data from TV Met, Bulgarian meteorological company that included hourly records. Tabular fuel moisture files were created using the fine dead fuel moisture values calculated for the BehavePlus analyses for 1-hr timelag 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 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.

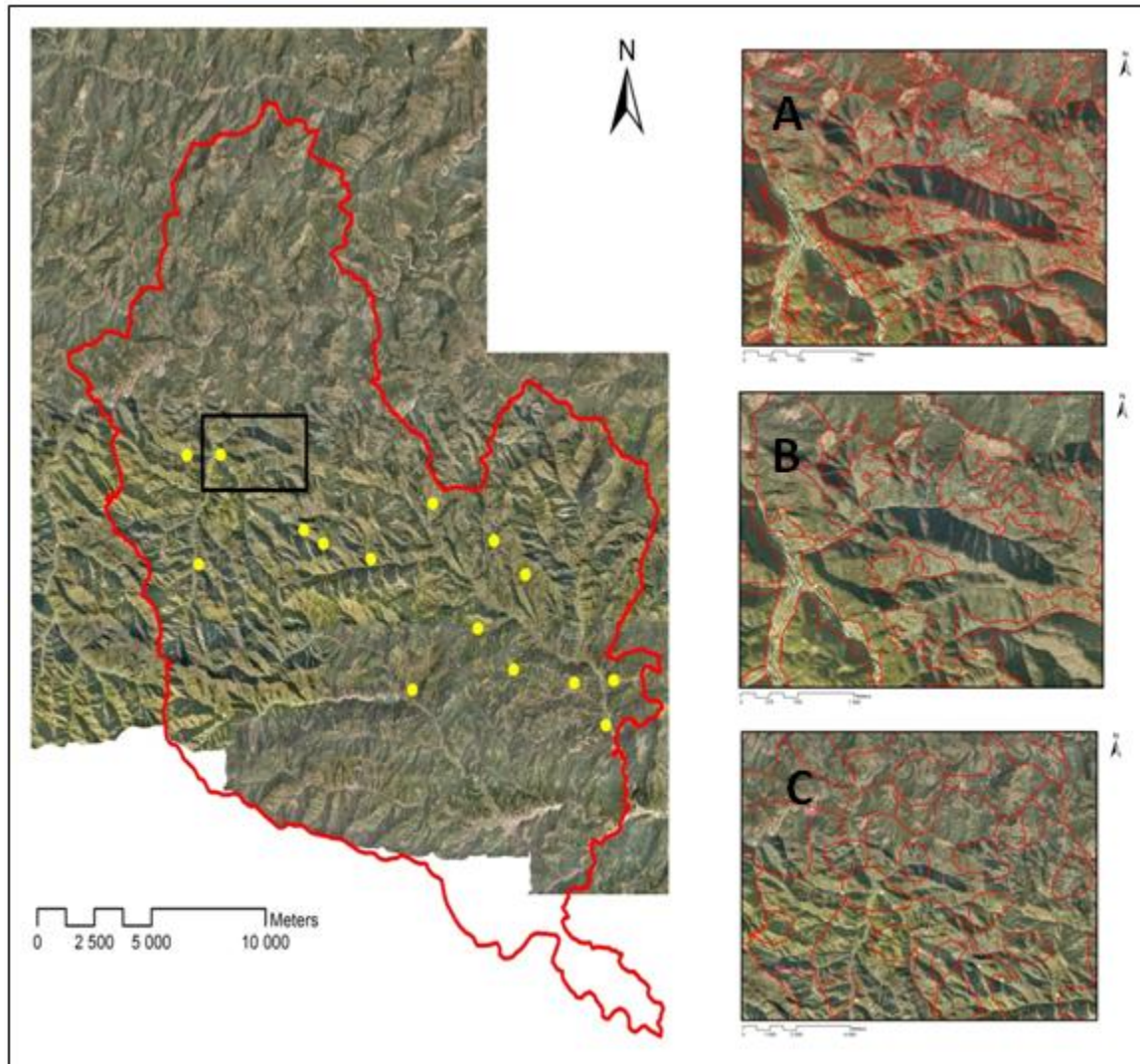


Figure 2: Location of the 15 fires (yellow dots) in the Zlatograd area that occurred in 2011-2012 that were used to develop fire behavior analysis methodology. The outline of the municipality of Zlatograd is shown in red, with the orthophoto imagery used to identify canopy cover underneath. The black box indicates the location of the three inset maps on the right. Inset maps are: A) Zlatograd forestry polygons; B) Corine land cover polygons; and C) Bondev vegetation map polygons.

Results

Although the fifteen case study wildfires were not large, we were able to establish a process to compile the necessary inputs and complete fire behavior analyses using both BehavePlus and FARSITE. As the first attempt to complete these types of analyses for Bulgarian landscapes, we successfully navigated the challenges of assembling input data for a location where data sources are scarce. We also successfully applied both modeling systems outside of the environment in which they were developed. In doing so, we learned important lessons (see below). More importantly, though, we were able to establish a defined methodology for the OUTLAND project for future use of BehavePlus and FARSITE for wildfires in Bulgaria.

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 3).

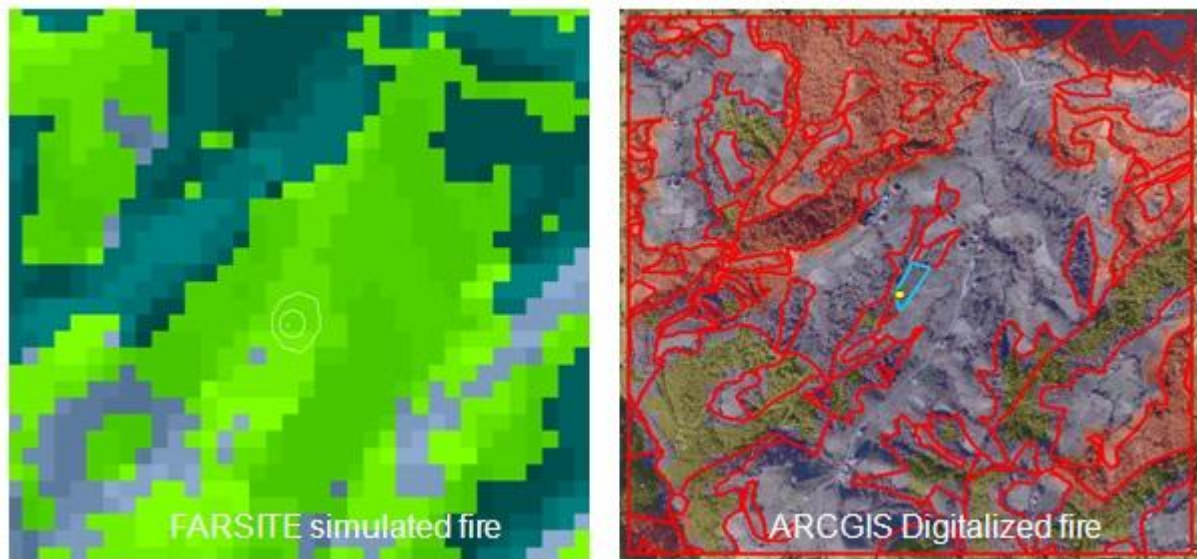


Figure 3: FARSITE run for a grassland fire

An example of another fire we modeled in FARSITE using standard fuel models was a fire that occurred on March 29, 2012 in a beechwood forest. This fire burned for a total of four hours, starting at 1400 and ending around 1800, and burned a total area of 0.5 ha. Wind speeds were variable throughout the burning period as they were quite high during the early afternoon but tapered off throughout the day. In this case we used the following input parameters in FARSITE:

Fuel moisture values: 3% (1-hr), 4% (10-hr), 5% (100-hr), 40% (live herbaceous) and 70% (live woody);

Daily maximum temperatures: 7-10°C;

Daily minimum relative humidity: 36-40%;

Winds: generally from the north-northeast at 10-2 k h⁻¹

The projected fire size from FARSITE was 0.9 ha. Based on the close proximity of a village to the fire location (figure 4) it is quite reasonable to assume that local residents responded to the fire in a volunteer capacity; these suppression actions are not accounted for in the FARSITE

analysis. Decreasing winds through the afternoon may have significantly helped suppression activities.

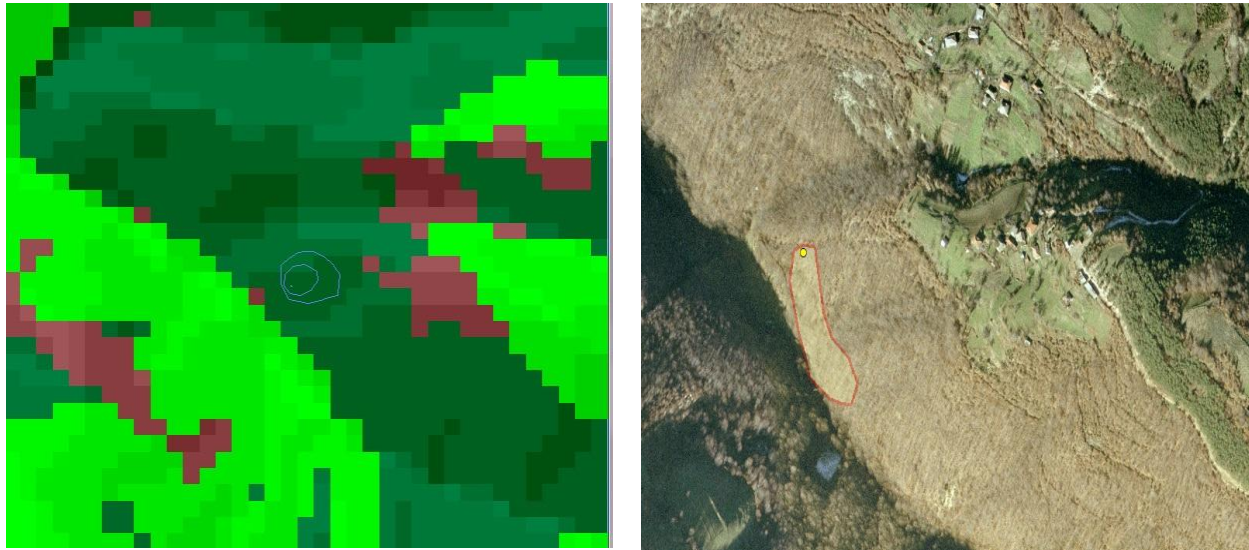


Figure 4: FARSITE run for wildfire that burned in a beechwood forest

Lessons Learned

In the presented work we describe the application of FARSITE and BehavePlus fire behavior systems for a test area in the Zlatograd municipal territory of Bulgaria, something that has never been accomplished in Bulgaria. These simulations will serve as a foundation for future work. Bulgaria is not nearly as data rich as other countries and therefore the process developed reflects the types of data readily available. This methodology was developed to be flexible and make use of potential future sources of data.

Through this process, we were able to identify shortcomings in the fire behavior systems, most notably how they deal with metric data. Applying fuel models developed elsewhere can be difficult, yet we were able to identify standard fuel models from the U.S. that seem compatible with Bulgarian surface fuels and also identify gaps in the standard fuel models indicating the need for custom fuel models for the Zlatograd area. Weather data is expensive in Bulgaria as it must be purchased; having better access to weather station data would more readily allow for future simulations without the monetary burden currently involved. Future simulations would require fewer assumptions if data specific to each fire were available, including the suppression actions and specific fire weather observations.

Conclusions

The work presented here represents the initial step in completing analyses to predict fire behavior and growth of recent wildfires in an area of Bulgaria. Information that would be valuable in refining this work in the future includes observed fire weather, observed flame lengths and rates of spread, direction of growth, suppression actions, and documentation of pre-fire vegetation. The availability of this data would allow comparison of modeled fire behavior with observed fire behavior, and improve the accuracy of computer-based simulations.

Preliminary fire behavior analyses identified which variables may need to be modified, for example which vegetation types may require creating custom fuel models. Through an iterative trial and error process, it became apparent how Bulgarian data can be used to perform

simulations in BehavePlus and FARSITE, including the inherent nuances within each of these systems in working with metric data.

Acknowledgements

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