Validation and calibration of Farsite vegetation fire growth simulation software on several Adriatic islands

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ABSTRACT: We have used the vegetation fire growth simulation software Farsite to simulate the spatio-temporal evolution of two historical vegetation fires that occurred on the Adriatic islands of Korčula in 1998 and Lastovo in 2003. The spatial, vegetation, meteorological and agrometerological data have been obtained from various national agencies. The historical fire perimeters have been collected by firefighting commanders. By selecting the appropriate fuel models from the extended set of fuel models in Farsite, we have obtained a very good match between the simulated fire perimeters and observed ones. The sets of fire models corresponding to the Mediterranean vegetation on these two islands will be used as the starting point for the calibration of Farsite for the operational use in the Croatian firefighting organization.

1 INTRODUCTION

Vegetation fires occur frequently on the Croatian coast of Adriatic Sea, particularly during the summer months. In this densely populated area, prompt and efficient fire suppression and control is essential in order to prevent casualties and significant material losses. However, it is not always easily achieved, as the dry climate and highly flammable Mediterranean vegetation support high fire spread rates while complex relief and frequent, even diurnal, wind changes prevent reliable spread direction estimates. This condition resulted in numerous large-area fires in recent years. The problem of fire suppression management is even more important on Adriatic islands, where local volunteer firefighter crews have to be supplemented by external firefighting resources in the case of large-area fires and the correct estimate of these resources is essential for successful fire suppression. The use of fire growth simulation software, which is capable to predict the spatio-temporal fire spread in conjunction with reliable spatial and meteorological data and proper vegetation fuel models might help firefighting commanders to manage the fire suppression more efficiently.

Here we present the results of the first simulations of the historical vegetation fires on the Adriatic islands. This work represents the first step towards the simulation-based operational support to firefighting organization in Croatia. In this respect, it encompasses more than just the simulation and aims at establishing the system for the data collection, simulation and dissemination of the results in collaboration with relevant state agencies, academic institutions and firefighting organization (Bajić, Miloslavić and others 2008).

2 INITIAL PROCEDURES

The first step in the preparation for the simulation of the fire growth was the selection of the appropriate simulation software package. The choice of Farsite (Finney 1998) has been based on the comparative study of several fire growth simulation software packages released in 2001. by CLIFF project of the IST FP5 programme. According to this study, the Farsite software is the most versatile, accepting detailed spatial variations in the relief and vegetation as well as spatio-temporal variation of the meteorological and agrometerorological (fuel moisture) conditions. Also, it featured the most advanced treatment of multiple fire occurrences, merging/overlapping fire lines and enclaves. Various simulation results can be exported in several formats accepted by standard GIS software. Finally, it is released free of charge and, apart from the Windows-based executable, parts of the code that perform the actual computing are available as well. All this makes Farsite a very good choice for the initial study/simulation of actual historical fires.

Next we have verified that the various data sets required by the software package are available and identified the sources of these data. The official topographic maps at scale 1:25 000 (TK25) and 25 m resolution digital terrain models (DTM25) can be obtained on request from the State Geodetic Administration. The official vegetation maps, created according to the Habitat classification of the Republic of Croatia, are available from State Institute for Nature Protection, on-line and on request. The meteorological and agrometeorological data are available from the Croatian Meteorological Service. The level of historical or prognostic data details we are interested in requires additional processing, however, for the state agencies it is available free of charge upon agreement.

The data on the evolution of the fire growth in time for the historical fires we have obtained from the firefighting commanders. This level of the fire data collection is beyond the official requirements and depends on voluntary work by commanders. It cannot be accessed through official reports and it has to be retrieved from the local firefighter archives or even personal archives.

3 DATA SETS, FORMATS, CONVERSION PROCEDURES AND EXAMPLES

The historical vegetation fires that we have studied in this work occurred on the island of Korčula in 1998. and on the island of Lastovo in 2003. We have obtained scanned topographic maps with the fire perimeters at different times, every few hours for Lastovo, where the fire have been contained within one day, and daily for Korčula, where the fire have been contained after 10 days. The scanned topographic maps have been georeferenced in Autodesk Map. This was followed by a manual vectorization of the fire perimeter lines and by exporting of all lines to the shape file format, suitable for Farsite.

The obtained DTM data are based on Bessel's ellipsoid, 6th zone of the Gauss-Krüger projection. As the DTM data are distributed according to the sheet line system Croatian national topographic map TK25, several sheets had to be combined in IDRISI to cover the entire surface of the islands. The aspect and slope data have been computed from DTM in IDRISI and exported as raster data in the GRASS ASCII format. In order to import them in Farsite, minor changes in the file header had to be made.

Additionally, the main and secondary roads, rivers and buildings have been vectorized from topographic maps using the same procedure as for the fire perimeters. The position of some of the main roads was necessary for the emulation of important firefighting activities which effectively present barriers for the fire spread.

The vegetation maps have been derived from the habitat maps of the Republic of Croatia. We obtained the maps in the shapefile format, geocoded in the Gauss-Krüger projection on Bessel's ellipsoid, zone 5. The attribution is according to the the Habitat classification of the Republic of Croatia, which is compatible with the CORINA Landcover classification and the smallest attributed area is 9 ha. The two islands are covered with about 10 different habitat types. The important ones are the urban/industrial areas, cultivated agricultural habitats, meso- and thermo-Mediterranean short-grass grasslands, Adriatic lowlands garrigues and meso-Mediterranean woodlands of mixed broadleaved and coniferous evergreens. The maps have been transformed in IDRISI to match the projection and the extents used in DEM and the attribution has been converted to the simple numbers with appropriate legends. Then they have been converted to rasters and exported in the GRASS ASCII format.

The fire spread in the woodlands of Lastovo and Korčula proceeded mostly through the active crown fire, as witnessed by the fire commanders at the fire sites. In order to include it in the simulation, additional themes for Firesite have been created from the vegetation map, describing the canopy characteristics. For the woodland areas the canopy cover has been set to 100%, while for the other areas to 0%. Likewise, the crown height has been set to 10 m and base height to 1 m, according to the rough estimates based on the experience of firefighting commanders we have collaborated with. The crown bulk density value has been set to 0.1 kg/m^3, a density at which the crown fire remains active regardless of the spread rate.

The meteorological data required by Farsite are the daily temperature and humidity maxima and minima, precipitation and cloud and the temporal variation of the wind speed and direction. For both Korčula and Lastovo these data had to be transcribed from analog meteorological station outputs. The wind speed on the beaufort scale and the cardinal wind direction has been recorded on Korčula in 1998. at 7, 14 and 21 o'clock daily. The wind speed has been converted to the average values in m/s for each class on beaufort scale, while the cardinal directions have been converted to azimuths. On Lastovo the wind speed with the 1 m/s resolution and wind direction with 11.25° resolution has been recorded every 10 min. Our collaborators at the Croatian Meteorological Service have verified the recorded wind variations against the ALADIN based prognostic values for the corresponding periods. Moreover, additional numerical simulations based on the more realistic MM5 model have been performed on the 1 km grid, as we wanted to check if there have been any significant spatial variations of the wind and to include them in the simulation. However, neither the direction nor the speed of the wind in the simulations have been affected by the relief, so we used in the simulations the recorded values as reliable for the entire area.

The initial fuel moistures have been calculated from the moisture codes based on the Canadian Forest Fire Weather Index (FWI) System, according to the standard conversion formulas (Van Wagner 1987). The moisture codes are released daily by Croatian Meteorological Service. The standard fuel sizes are categorized in Farsite according to the time lag of the moisture changes as 1hr, 10hr and 100 hr and they do not correspond entirely to the fuel types described by fine fuel, duff and drought codes in FWI, however this is the only available estimate that we have had. For the island of Lastovo the 1hr fuel moisture was 2%, the 10hr moisture 3% and the 100hr moisture 5%. For the island of Korčula the corresponding moistures have been 3%, 5% and 8% for 1hr, 10hr and 100hr sizes.

It should be noted that such fuel moisture estimates are suitable for the vegetation and conditions in Canada for which FWI has been developed and they can vary substantially depending on the species producing corresponding fuel. Moreover, the values of the live vegetation moisture, required by Farsite, are not included in FWI and we have adopted in our simulations some previously published values (Arca 2007, Duguy 2007). Fortunately, systematic measurements of the fuel moistures in various meteorological conditions for characteristic Croatian vegetation are in progress.

4 SIMULATION PROCEDURE AND RESULTS

With all required data available, the simulation procedure was rather straight forward. The spatial resolution has been set to 25 m corresponding to the raster cell size. The time steps have been set to approximately 1/10 of the typical time interval between the observed fire perimeters, 10 min for Lastovo and 1 hour for Korčula. The crown fire has been modeled according to the Scott and Reinhardt method. Torching and spotting was excluded from the simulation, as it required a lot of computational time and the results were not entirely reproducible. Other parameters not previously defined, such as fire acceleration, fuel moisture calculation intervals, and canopy foliar moisture have been adopted according to the values preset in Farsite.

There are only several fuel models predefined in Farsite for each type of vegetation (grass, shrub, woodland) which is present in the vegetation maps of two islands, particularly if the corresponding climate type is taken into account. We have tried various combinations of available fuel models for corresponding vegetation types in order to match as closely as possible the fire perimeters observed after given periods of time. Eventually we have obtained very good agreements between the simulated and the observed fire perimeters at first two time intervals, as presented in Figure 1. for Lastovo and in Figure 2. for Korčula. At longer times, however, the simulated perimeters exceeded the observed ones. The figures represent actual maps from Farsite which combines vegetation map draped over DTM with road and man-made object map. Legends, toponyms and ignition point symbols have been added afterwards.

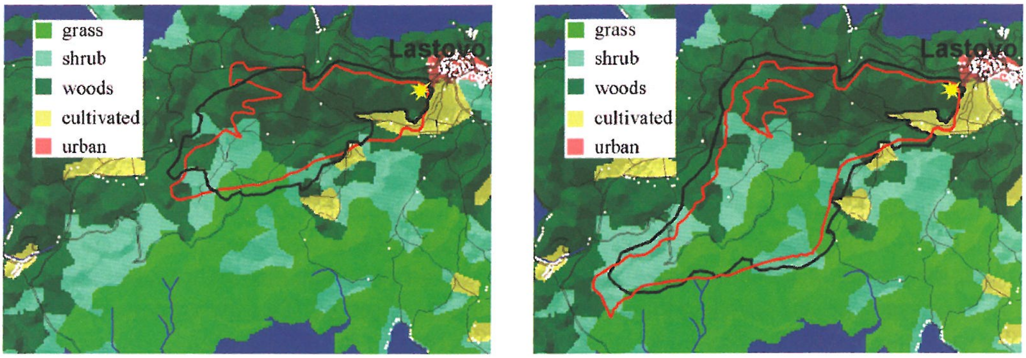

Figure 3. (in color online) The excerpt of the vegetation map of Lastovo draped over the DTM with the observed (thick red line) and simulated (thick black line) fire perimeters after 3 hours (left panel) and after 9 hours (right panel). Yellow star represents the ignition point, thin black lines represent roads and white squares man-made objects.

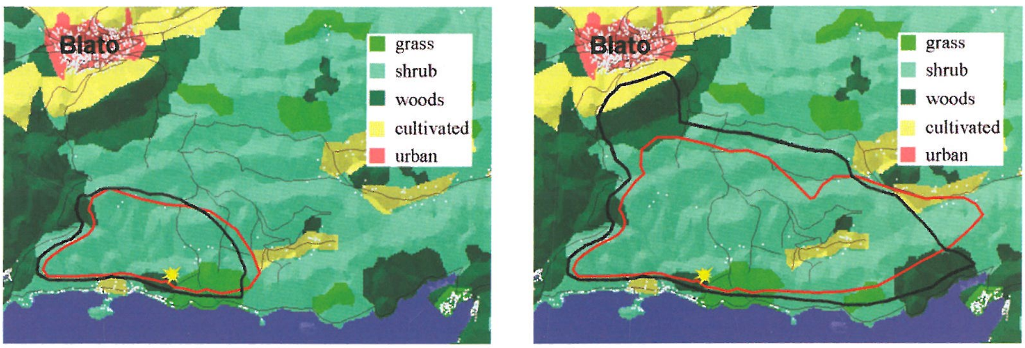

Figure 4. (in color online) The excerpt of the vegetation map of Korčula draped over the DEM with the observed (thick red line) and simulated (thick black line) fire perimeters after 13 hours (left panel) and after 39 hours (right panel). Yellow star represents the ignition point, thin black lines represent roads and white squares man-made objects.

The most suitable fuel models that produced presented simulation results are as following. For the woodland it was the very high load, dry climate timber-shrub fuel model (TU5 of Scott 2005) for both islands. For the grass it was short, sparse dry climate grass (GR1) for Lastovo and low load dry climate grass (GR2) for Korčula. For the shrub it was the low load dry climate shrub

(SH2) for Lastovo and very high load dry climate shrub (SH7) for Korčula. Urban and cultivated areas have been declared as nonburnable, the simulated perimeters deviated from observed ones at longer times.

5 DISCUSSION

Presented results demonstrate a very good correspondence between the observed and simulated fire perimeters for two historical vegetation fires, with all required parameters given within the available accuracy and with appropriately selected fuel models corresponding to the climate of these islands. They suggest that the vegetation fires on the Croatian coast of the Adriatic Sea can indeed be successfully simulated with the fire growth simulation software Farsite.

However, there are several issues that have to be addressed here and in the future development of the simulation-based operational support to firefighting organization in Croatia. First of all, the results of the simulations at times longer than presented deviate from the observed fire perimeters, i.e. the simulated fire spreads faster than observed. This discrepancy originates almost certainly from the fire suppression activities during the fire. Unfortunately, the prevailing firefighting method of the ground firefighting in Croatia is the use of the fire retardants, even in the case of wildland fires, and this method is not incorporated in the Farsite fire spread model. Thus, at longer periods of time when the firefighting activities start to affect substantially the fire spread, Farsite is not capable to predict is successfully. The use of Firesite as the operational support should therefore be restricted to the evaluation of the initial, still uncontrolled, fire spread, which still has substantial merit, or the Farsite model should be extended to support the ground fire suppression with retardants as well. Although this latter approach seems to be quite complicated, we believe that the basic modification would consist of adding the spatial and temporal variation of the fuel moisture content corresponding to the ground crew position and fire suppression capacities.

In this respect, even the fuel model parameters we have obtained from the simulations of the initial fire spread should be taken with caution. It is particularly evident in the different choice of the fuel models for nominally same grass and shrub vegetation on two islands. It is not possible any more to determine accurately the state of the vegetation in these two cases prior to the fire and to determine whether the difference in the fuel model selection corresponds to the actual differences in the vegetation or it is a consequence of the fire suppression. The only indication we have that the difference in the vegetation might be real is the fact that the same area on the Lastovo island has burnt in 1998. i.e. 5 years before the fire that we have simulated. It is possible that the vegetation has not completely regenerated in this period so the choice of fuel models with smaller load seems reasonable.

The second issue is the determination of the actual fuel moisture content, which is an important parameter whose small variation can affect considerably the fire spread. As we have already mentioned, the fuel moisture contents we have used are based on the Canadian FWI System which is not necessarily appropriate for the Mediterranean vegetation. The ongoing development of the proper Croatian system will lead to better estimates of the moisture content for different fuel types. On one hand, it will improve the predicting power of simulations, but on the other it will require the re-evaluation of the appropriate fuel models.

The third issue, which has been already partially addressed above, is the precise determination of the vegetation cover characteristics. As we have shown, different fuel models that we have used for the same vegetation types in the simulations probably originate from the different cover characteristics such as fuel load and depth. The more information is available about such variations in the regions where Farsite will be used for operational support, the more appropriate fuel models could be used and the simulations will be more reliable. A new method that combines the imaging spectrometry and LiDAR data (Koetz and others 2008, Mutlu and others 2008) enables a detailed assessment of the spatial patterns of fuel types as well as the three-dimensional structure and state of the vegetation. The initial attempts to introduce the airborne multisensor imaging in the reconnaissance and surveillance procedures in the crisis situations and the protection of the environment have been already achieved (Bajić, Gold and others 2008) and the results are promising.

Finally, although the results obtained for the two islands are promising, these are just the first steps towards the operational use of the fire growth simulations in the firefighting activities. A much wider set of historical vegetation fires will have to be analyzed in order to create a reliable data base of the vegetation cover of the Adriatic coast of the Republic of Croatia with the corresponding fuel models. Unfortunately, the detailed information on the spatial and temporal evolution of historical fires, as we already mentioned, is sparse. Therefore the further development will crucially depend on the ability to survey systematically the new vegetation fire occurrences and to collect as much data required for the simulations as possible. In this respect, the collaboration with the fire fighting organization and particularly with field commanders is essential. The field commanders can authorize airborne surveillance of the fire perimeter, help in the evaluation of the volume and the impact of the fire suppression activities and instruct the field crew to monitor the spatial and temporal evolution of fire perimeter. On the other hand, as the simulation system evolves, they can eventually benefit from the results of the simulations and help in the evaluation and the validation.

We have already presented the simulation software and the results from this work to the experienced firefighting commanders and received a lot of interest and support for further development. Even in the present state the software can serve for the education and training. Recent contacts with the National protection and rescue directorate and acceptance of the project proposal submitted to the Directorate provide the possibility to continue our work and to achieve the final goal.

6 CONCLUSION

We have demonstrated in this work that the vegetation fire growth simulation software Farsite can be used to simulate the spatio-temporal evolution of the vegetation fires on the Croatian coast of the Adriatic Sea, provided that all required spatial, vegetation, meteorological and agrometerological data are collected and the appropriate fuel models are selected. In the case of two historical vegetation fires that occurred on the Adriatic islands of Kor-čula in 1998 and Lastovo in 2003. a very good correspondence between the observed and simulated fire perimeters for two historical vegetation fires has been obtained. For the operational use in the Croatian firefighting organization, however, several advancements are required. The fire spread model used in Farsite has adapted to the fire fighting techniques used in Croatia and the vegetation data base with corresponding fuel models has to be created and verified through the simulation of the systematically monitored new vegetation fire occurrences.

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