Web service tools in the era of forest fire management and elimination

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ABSTRACT

Wildfires in forests and forested areas in South Europe, North America, Central Asia and Australia are a diachronic threat with crucial ecological, economic and social impacts. Last decade the frequency, the magnitude and the intensity of fires have increased even more because of the climate change. An efficient response to such disasters requires an effective planning, with an early detection system of the ignition area and an accurate prediction of fire propagation to support the rapid response mechanisms. For this reason, information systems able to predict and visualize the behavior of fires, are valuable tools for fire fighting. Such systems, able also to perform simulations that evaluate the fire development scenarios, based on weather conditions, become valuable Decision Support Tools for fire mitigation planning. A Web-based Information System (WIS) developed in the framework of the FLIRE (Floods and fire risk assessment and management) project, a LIFE+ co-funded by the European Commission research, is presented in this study. The FLIRE WIS use forest fuel maps which have been developed by using generalized fuel maps, satellite data and in-situ observations. Furthermore, it leverages data from meteorological stations and weather forecast from numerical models to feed the fire propagation model with the necessary for the simulations inputs and to visualize the model’s results for user defined time periods and steps. The user has real-time access to FLIRE WIS via any web browser from any platform (PC, Laptop, Tablet, Smartphone).

Keywords: Fire propagation modeling, Web-based Information System; on-line simulations, what-if scenarios

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1. INTRODUCTION

Forest fires are considered one of the most important natural hazards globally. South Europe, North America, Central Asia and Australia are the main areas of the planet that are affected annually with very large variations in the fire seasons [1]. This natural hazard is a permanent threat for the natural resources with critical ecological, economic and social impact, emerging from fire occurrence effects such as loss of lives and goods, damages to wildlife habitats, soil erosion and degradation of the watersheds. The latter two effects are also responsible for catastrophic flash flood events that may happen during the winter, following large summer fires. During the last decade, the frequency, the size and the intensity of the fires in forests and forested areas has increased greatly as a consequence of the global warming and the degradation of natural resources [2] in the "altar" of human’s need for material possession. In South Europe, every year, wildland fires reduce the forested areas at a remarkable rate [3]. The last decade, in the European countries of the Mediterranean basin, the number of ignitions and the total areas affected by the wildfires, have increased exponential. The year 2007 counts a negative milestone in the era of wildfires in the South Europe, with more than 300.000 ha of forests reported burned [4].

Even if forest management authorities and Regional Civil Protection Agencies continuously increase their efforts in forest fire fighting, thousands of hectares of forests are lost every year. To prevent the impair of forest ecosystems, forest
Managers and civil protection agencies have to make efficient use of the modern technology to address the various fire management problems. The availability of new technologies like geo-informatics (GPS systems, digital cartography, GIS systems), sensor networks (automatic remote weather stations, smoke detection sensors, remote infrared cameras, 3G/4G mobile network, smartphones, tablet pc with 3G network) and Earth Observation (EO) products (high spatial and temporal resolution open access satellite imagery) can contribute to a more effective organization for the environmental protection [5]. The efficient management of the fires is crucial in the early stage of fire ignition. The civil protection mechanisms need real-time information, concerning the potential spread of the fire frontal in order to plan for an effective control and containment. Such information requires the efficient combination of an interdisciplinary research, technology, innovation and the development of a consistent approach to assess the fire risk (the product of the probability of occurrence of a fire and the consequence of its occurrence, e.g. financial loss or death/injury) and hazard (the potential of injury or damage from fire), along with prompt and a reliable fire management information system.

New technologies, related to geo-information and electronic data capture/transmission of the collected information from remote areas, have a strong potential to contribute to a more effective organization for the environmental protection [6]. The objective of this study is to discuss the role of the Web-based information provision for an efficient prevention planning and forest fire management by presenting a Web-based Information System (WIS) developed in the framework of the FLIRE (Floods and Fire risk assessment and management) project, a LIFE+ co-funded by the European Commission research (LIFE11ENV/GR/975). The innovation of this WIS is mainly related to:

- the Web-based access (thus the no need of the installation of a software, or plug-in support software at the web browser and the maintenance of the hardware components) by any kind of operation system (Windows, Linux, Mac OS, Android);
- its distributed architecture; and
- the possibility of remote access from the fire management information services, by means of ultrabooks, tablets and smart-phones that the end users can use even in the field during the early stages of a fire incident.

The abovementioned characteristics are important to support fire mitigation planning and to the control of the fire during the very first steps of its propagation.

2. CASE STUDY AREA

![Figure 1. The study area of catchment area of Rafina city.](image-url)
The web-based platform - called FLIRE WIS - was designed to support wildfire early warning and civil protection by on time information sharing with the appropriate agencies. The prototype is currently applied to a periurban area in East Attica, Greece, but is easily transferable to other locations and broader areas. The study area is the catchment basin of Rafina municipality, a peri-urban area of 123 km², located in Attika region, Greece (Figure 1). It is a recently developed area, close to the "Eleftherios Venizelos" International Airport of Athens, as well as to the Attiki Odos highway (A6 highway). This highway connects the study area with the city of Athens, favoring urban sprawl [7]. It is a typical Mediterranean area, with extensive assets and lives at risk, that extends over approximately 200 km² underwent rapid and uncontrolled urbanization during the last decades and is particularly prone to both flash floods and forest fires resulting in its gradual but dire ecological degradation. This degradation has significant consequences for the almost 5 million inhabitants of Athens, who rely on these areas for recreation in the summer period, contact with nature and quality of life. The vegetation types found in area are a mixture of seasonal crops in the south, sparse cultivations of olive trees and vineyards. An extensive area of low vegetation in the north, an extended network of creeks which host riparian vegetation and a pine forest in the west and east part of the area, as well as some small islets of pines in the urban areas.

3. THE FLIRE WIS SYSTEM

The FLIRE WIS is a Web-based early warning and decision support system for an integrated forest fire management and weather information management. It is based on geo-informatics, spatial modeling, fire propagation modeling and EO data exploitation for fuel mapping. The FLIRE WIS consists of two different subsystems, geographical isolated, which are connected by the FLIRE server. The system has a distributed structure as shown in Figure 2. The FLIRE server uses FTP tools and web services technologies, whereas a Graphical User Interface (GUI) was developed based on the user's goals and needs, skills and experience. The FLIRE WIS consists of four modules, described in more detail below:

1) the Weather Information Management Tool (WIMT), which handle, manage and provide to the models the necessary weather data;
2) the Early Fire Warning System (EFiWS), which provides the user the control of the models;
3) the FLIRE server, which unify the above tools; and
4) the GUI, which is the front end of the WIS.

![Figure 2. The distributed architecture of the FLIRE WIS system.](image)

3.1 The FLIRE Server and the GUI

The FLIRE Server unify the components of the system and therefore are accessible via the GUI from the FLIRE web site (www.flire.eu) for authorizes users such as the Civil Protection Authorities, Fire department services and Forest services.
A specific password protected area has been designed for the access of this system. Having as the backbone a windows-based server, the FLIRE WIS tools are implemented in five tabs, each one playing a different role in the system:

- Spatial data visualization board - Map (A)
- Weather Forecast Data (B)
- Weather Stations (C)
- Fire Management System (D)
- KBDI control board (E)

Tab (A) has the role of the visualization of the spatial data (Figure 3). Here the user can visualize the results of the fire modeling, the weather forecast grid for selected dates, the weather stations, as well as other available spatial data like Land cover, Land-use datasets, a polygon that includes the area of the project, satellite images from Google Earth and flood risk maps. Tabs (B) and (C) provide the weather forecast data, in both XML and KML formats, as well as the weather stations data for the time the user access them. Tab (D) provides options for G-FMIS parameterization. For this tab, the options are related to the following elements:

- the ignition point of the fire accessed in tab A,
- the updated weather observation data in tab C,
- the using weather forecast data for the fire simulation model parameterization.

The latter is necessary when the user wants to explore what will be happen in a case of a fire at a specific location of the study area, at a specific time within the next 24 hours (what-if analysis). Tab (E) provides to the users the ability to see the KBDI values for the project area either by using weather stations data or weather forecast data.

![Figure 3. The Map of the FLIRE - WIS system.](image_url)

### 3.2 The Weather Information Management Tool

The role of the WIMT is to retrieve, handle, manage and utilize the available, for the study area, weather data that are provided by three different sources:

- Weather forecast data from the National Observatory of Athens (NOA)
- Meteorological stations from the National Observatory of Athens (NOA)
Meteorological stations from the National Technical University of Athens (NTUA)

For the weather forecast data, an operational Numerical Weather Prediction (NWP) system consisting of global atmospheric models run typically at horizontal resolution ranging from 20 to 50 km and of mesoscale limited area models with horizontal resolution ranging from 5 to 10 km. The MM5 (Fifth-Generation Penn State/NCAR Mesoscale Model) model’s simulations are used in FLIRE WIS. MM5 runs operationally, once per day, following a three-nest strategy with 24-km, 8-km and 2-km horizontal grid increment [8]. This modeling effort follows the worldwide trend to use increasingly higher resolutions with NWP models at operational basis, following the significant improvement of computing capabilities at prices that are continuously decreasing. Three one-way nested grids are defined and used at an operational basis for the needs of FLIRE project. MM5 model runs once per day, initialized at 00:00 UTC. Grid 1 simulation lasts 72 hours, Grid 2 starts at t+6 with a total simulation time of 66 h and finally Grid 3 starts at t+6, with a total simulation time of 42 h. Therefore, Grid 3 provides every day detailed weather forecasts for the same day and the following day, at 1-h interval. This high spatial and temporal resolution of Grid 3 data allows the provision of rainfall and wind forecasts in the FLIRE project. The system provides every day detailed weather forecasts for the same day and the following day, at hourly intervals. The produced forecast for a grid of 40 x 45 points in the project area (80 km x 90 km) is stored in the form of text files in the server of NOA and retrieved by WIMT using the FTP protocol. The weather forecast data are used for the implementation of the "what-if" scenarios for the G-FMIS and for the daily calculation of the KBDI index, as a fire forecast tool.

From the in situ network of the weather stations, the following in-situ observations are provided:

- air temperature (in °C)
- relative humidity (in %)
- wind speed (in km/h)
- wind direction (in °)
- rainfall (in mm)
- height (in meters)

These measurements (Figure 4) are provided every 10 minute by the Hydrological Observatory of Athens (HOA, http://hoa.ntua.gr/), which homogenize, manage and store the data from both NOA and NTUA stations networks. These data are retrieved by WIMT via a FTP pool approach in XML format and stored in the FLIRE WIS weather spatial database. The weather data from the stations are used as input in the fire models (G-FMIS and KBDI).

Figure 4. The measured parameters of the weather station.
3.3 The Early Fire Warning System, the Geographic Fire Management Information System and the Keetch-Byram Drought Index

EFiWS is comprised by the two operational relative fire management components:

- the G-FMIS (Geographic Fire Management Information System), which handle the fire propagation modeling;
- the KBDI (Keetch-Byram Drought Index), which is a the fire risk assessment indicator.

G-FMIS is the Forest Fire Management model [9], [10], [11], [12], which includes a forest fire simulator, based on the BEHAVE [13] fire behavior model. It uses a modified version of the shortest path algorithm [14] adapting it to the simulation of forest fire propagation. G-FMIS was redesigned as a Web-service and is used by the FLIRE WIS for providing fire risk assessment and fire propagation simulations. It utilizes forest fuel maps, as a prerequisite of forest fire propagation simulation and fire behavior assessment. Detailed fuel maps have been produced for the study area, based on EO-derived land cover/use mapping (Figure 5). Landsat 8, carrying the Operational Land Imagery (OLI) and the Thermal Infrared Sensor (TIRS), a medium spatial resolution (30m) multispectral image [15] has been analyzed by implementing the state-of-the-art classification techniques in order to produce the landuse/landcover dataset of the study area, suitable for the production of a detailed fuel mapping dataset. The classification scheme was based on the fuel mapping requirements, as well as on its class identification efficiency [16]. Image visualization techniques were used to assist the visual interpretation as well as an intensive fieldwork campaign. False color composites RGB: 5-4-3 for OLI, were interpreted. These image band compositions clearly depicted the forest vegetation in dark red, the water associated vegetation in bright red and the urban surface materials in light bluish tones, while it was difficult to distinguish dry cultivated areas and low vegetation. The latter one was possible using the true color combination RGB: 4-3-2 for OLI. Urban surface materials were split into two categories a) bright impervious surfaces, which includes the bright reflectance from buildings; and b) dark impervious surfaces which includes roads, sidewalks, driveways, parking lots and industrial areas. During the fieldwork campaign, data from all the defined classes were collected, by means of GPS and photographic cameras which record the image coordinates (the location from which the image has been captured in WGS84) as well as the direction of the camera lens (in degrees). These data were split in two parts (a) one proportion for the training of the algorithm for the image classification and (b) one proportion for the accuracy assessment of the product of the classification. Pixel-based Support Vector Machines (SVM) algorithm was selected and used among others [17] due to its superior performance compared to other pixel-based algorithms [18], [19] on medium spatial resolution satellite images. In our study, the SVM classification results have an overall accuracy of 89.23%. Meanwhile, it achieved the separation of isolated structures within the vegetated areas as well as it delineated the riparian vegetation with great accuracy, two elements of the study area, important in the case of fire.

The fire risk assessment service operates on a daily basis pulling meteorological data from the WIMT module. For the needs of this project, two fuel models were combined and used. The Northern Forest Fire Laboratory (NFFL) system [20] which is the most common and well-know fuel model, taking into account the vegetation structure and characteristic of the North-American floras and the one that developed in the framework of the Prometheus project [21]. It is a fuel type classification system, which was developed to better represent the fuel characteristic of the Mediterranean ecosystems. This classification, which includes seven fuel types, is principally based on the height and density of fuel, which directly influence the intensity and propagation of wildfire. Each fuel type is characterized by a number of fuel parameters used in the fire propagation modeling.

KBDI is a cumulative index that provides indication concerning the conditions contributing to the flammability of the vegetation and its daily variation due to meteorological conditions [21]. It is a soil/duff drought index that ranges from 0 (no drought) to 800 (extreme drought) and it is based on the soil capacity in 8 inches (200 mm) of water. The depth of soil required to hold 8 inches of moisture varies. This index is cumulative, based on the previous day value and it is calculated once per day, every morning, for each station that is located within the area of interest, using the meteorological data of the previous twenty-four hours. This index is also calculated by using the weather forecast data, for the implementation of a "what-if" scenario. There are four classes of fire danger associated to the respective range of KBDI values as follows:

- KBDI = 0 - 25: soil moisture and large class fuel moisture is high and do not contribute much to fire intensity. Typical of spring dormant season following winter precipitation.
• KBDI = 25 - 100: typical of late spring, early growing season. Lower litter and duff layers are drying and beginning to contribute to fire intensity.

• KBDI = 100 - 150: typical of late summer, early fall. Lower litter and duff layers actively contribute to fire intensity and will burn actively.

• KBDI > 150: often associated with more severe drought with increased wildfire occurrence. Intense, deep burning fires with significant downwind spotting can be expected. Live fuels can also be expected to burn actively at these levels.

These classes have been defined in proportion to the classification of the original values of KBDI (0-800) calculated using the US customary units. Therefore, these classes are tuned according to the observations in the area during the fire season. A daily risk map is published on the web using the system's web facility and the WIS platform. The WIS communicates appropriately stored messages to different groups of stakeholders when the index exceeds a predefined level. For both G-FMIS and KBDI systems, the user can utilize either the weather stations data for real time information, or the forecast data in order to develop "what-if" scenarios for fire mitigation planning, exploiting the weather forecasts related to strong winds and high temperatures.

Figure 5. Landuse/cover dataset from Landsat 8 in the project area.

For the operation of the G-FMIS, the user has to set the fire ignition point (or points) at the location (locations) of interest and then to update the system with the information from the weather stations that are in the project area. Also, the user can include more stations, outside but close to the boarders of the project area in order to predict more accurate the fire behavior. The user has the option to modify the waiting time for the response of the model. For the "what-if" scenarios development, the user can parameterize the WIS based on the information provided by the weather forecast model. Scenarios can be built either for the running and next day nor for previous days datasets, in order to simulate the behavior of a fire case that occurs in the area but was efficient eliminated. All the above are the necessary inputs for the
fire model. After these necessary steps, the user sends a request to the G-FMIS system and within the predefined waiting time, the fire model runs and returns a simulation on the spread of the fire for the next 3 hours or more as shown in Figures 6 & 7. For each point of the fire, parameters like the length of the flame and the step of the fire frontal are calculated and provided to the user in the form of a balloon at each point (Figure 8). The user has the option to increase, or decrease the duration of the simulation, as well as the waiting time for the response of the G-FMIS system. This is important in the cases of a low network connection (PSTN connection, 2G cellular network, overload of the network, etc.) in the area of interest.

**Figure 6.** The spread of the fire for the next 3 hours by applying one ignition point.

**Figure 7.** The spread of the fire for the next 4 hours by applying four ignition points.
KBDI index is calculated by using the station's data or the forecast data to support "what-if" analysis. For the operation of the system, the user has to define the first date for the KBDI as well as the number of the days for it (usually 3). By pressing the corresponding button, a table will appear with values per station (Figure 9) or per weather forecast point (figure 10). For the later, in the project area, a colored grid appears corresponding to the range of the values. For each area of 2 x 2 km of the weather forecast grid, the KBDI is calculated every day for the present and the next day. The scale of this index is presented by using four colors: green, yellow, orange and red denoting its severity. These colors are associated with the range of the KBDI values, as has been mentioned above. Green denotes range from 0 to 25, yellow from 25 to 100, orange from 100 to 150 and red over 150.

Figure 8. The information of the fire point in the form of balloon. (a) FLIN: Fireline intensity,(b) ROS: Rate of spread of the fire, (c) FLAME: Flame length & (d) TIME: Simulation step.

Figure 9. The table with the KBDI values for the weather stations for 3 days.
3.4 The FLIRE WIS performance

Figure 10. The color grid of the KBDI index by using the weather forecast data.

Figure 11. The response of the system after a cold start.

FLIRE WIS has been intensively testing for the performance and the reliability by accessing it from a variety of technological sources. Access from PC and laptop with wired and wireless network connections and different operation software, tablet and smartphones with 3G cellular network and different operation systems at remote areas on the field as well as from other remote areas have been tested. Also, the FLIRE WIS has been tested by the local fire department as well as from the Civil Protection in order to have an interaction for further improvements on the design and tools that are included. An important aspect of the FLIRE WIS is the ability to use weather forecast data for fire modeling. This gives
to the local authorities the potential to plan for an efficient elimination when the forecast information provide data that are prone for the fire, like strong winds with an extended period of dry hot days. In order to test the FLIRE WIS on its performance about the communication with all the distributed elements (WIMT, G-FMIS, KBDI), a series of 100 ignition point scenarios using weather data were used to evaluate the response time of the model and thus to be considered as a real time system. Fire model has a response after a cold start in about 27 seconds (mean value) with maximum at 61 seconds and minimum at 23 seconds (Figure 11). Only in a few cases the return of the results exceeded 35 seconds. Similar performance is also observed when using the weather forecast data that are stored in system’s databases.

4. CONCLUSIONS

The FLIRE WIS has been built as a web-based application that incorporates all modern tools and approaches. Open geospatial platforms, transformation of the models into web-services and implementation of the distributed architecture of the different components of the system have been used. One of the important advantages of the FLIRE WIS is that can be accessed by any computer hardware as well as operation system with no additional installation of any kind of software or plug-in at the web browsers. FLIRE WIS can be used either as a real-time information system to support fire mitigation or as a planning tool to support fire prevention. It can be turned out to a promising solution not only for fire protection agencies but also for Civil protection agencies as well as to other local authorities that are involved in natural disasters and is not feasible for them to obtain specific, expensive software and hardware as well as to be trained for the use and maintenance of them. The weather data, either from the forecast, nor from the stations, can be distributed to other tools for other natural disasters, like the floods and tsunamis and thus the “collect once - use for many” approach take place within this platform. 80% of the requests in the G-FMIS model return the data of the spread of the fire in less than 30 seconds. Such a response gives to the system the potential to be used as an invaluable tool, for both Forest Management Departments and the Civil Protection Authorities during the fire season, in the early depression of a fire in locations where fuel maps and weather information are available, due to its immediate provision of the necessary information. Moreover, similar tools need also to be developed for other natural disasters such as floods, to provide the information on time and therefore to prevent the loss of natural heritage values, properties and human lives. Finally, such tools have the potential to support the combined assessments of different hazards (like floods and fires), which is the ultimate goal of the FLIRE project.

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