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Cloud Computing in Geospatial Analysis of Wildfire Danger and Fire Growth

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Abstract: Today's wildfire fighting needs require information systems that are able to conduct fire danger and fire behavior predictions in a timely manner. Based on knowledge gained from participation in the EU-funded research project VENUS-C, the current article presents the conceptual approach and design of AEGIS; which is an under development, state-of-the-art IT system that integrates fire danger rating and fire growth modeling. The utilization of a cloud computing platform ensures scalability and promptness of the calculations. The efficiency of the proposed platform will be based on the Cloud's flexibility to scale up or down the number of computing nodes needed for the requested processing. In this context, end users will be charged only for their consumed processing time and only during the actual wildfire confrontation period. Reliable and fine-resolution maps regarding the forecasted fire danger for the next five days will be provided including ignition risk, values at risk/ vulnerability and burn probabilities. Fire behavior modeling is to be conducted in the Cloud by utilizing the Minimum Travel Time (MTT) algorithm of the fire behavior mapping and analysis program FlamMap.

Additional Keywords: Web GIS, parallel computing; wildfire prevention; fire behavior.

Introduction

Significant alterations in fire regimes have been occurred in the recent decades (Liou *et al*. 2010), primarily due to socioeconomic changes and climatic anomalies, increasing dramatically the catastrophic impacts of wildfires (Kontoes *et al*. 2012). Almost every summer massive wildfires break out in several areas, leaving behind severe destruction of forested and agricultural land, infrastructure and private property, and losses of human lives (Koubarakis *et al*. 2013). During the summer of 2010, widespread wildfires in western Russia burned thousands of hectares of rangelands and forested areas, and the fire-caused death toll exceeded 50 human loses (Stocks *et al*. 2010). In the Mediterranean basin, the number of ignitions and the area affected by wildfires has increased exponentially over the last 20 years (Pausas *et al*. 2008). In 2007, the fires that ravaged southern Europe were among the worst on history record with over 3000 km^2 of forests burned (Kalabokidis *et al*. 2013).

Being able to predict where and when a fire is most likely to strike is vital during wildfire seasons across the globe. Difficulties in confronting such natural phenomena include not only an assessment of their biophysical causes, territorial distribution and damage inflicted in time, but also their dependence on human socioeconomic activities and lack of the necessary technological infrastructure to mitigate their catastrophic effects (i.e. loss of human lives, resource and property damages) (Kalabokidis *et al*. 2013). As hazards and vulnerabilities are spatially and temporally distributed, risk is inherently a dynamic phenomenon; and risk assessment should address both the degree of risk and its spatiotemporal distribution (Chen *et al*. 2003). Therefore, fire risk management and fire behavior modeling require large volumes of data that change continuously over time and space, creating both the need and the opportunity to automate the tasks (Yuan 1997). These large volumes of data required for spatiotemporal calculations often rely on huge computer resources (i.e. processing power and storage). However, local civil protection agencies often do not own the required computer resources to conduct these heavy spatiotemporal calculations due to limited financial means. Furthermore, they may not have the expertise to utilize state-of-the-art fire management tools. Within this context, the operational necessity for a state-of-the-art, low cost and easy to use platform for forest fire management emerges.

The main objective of the present paper has been the conceptual approach and design of AEGIS; i.e. a currently under development Web GIS application that will integrate fire danger rating and fire behavior modeling. The proposed system may be a cost effective, easy to use forest fire management system, independent of commercial software for the end users. Based on an innovative computational model, the proposed approach will provide reliable, fine-resolution maps regarding the forecasted fire danger for the next five days including ignition risk, values at risk/ vulnerability and burn probabilities for several areas around the country of Greece. Computations in AEGIS will rely on cloud computing; this ensures scalability and efficiency of the calculations. Fire ignition danger computation in AEGIS will depend on the usage of several parameters in a quantitative calculation algorithm providing high geographical detail and the ability to refresh and recalculate the map with newly acquired data during the day. In addition, outcomes from existing international research such as the Minimum Travel Time (MTT) algorithm will be integrated into AEGIS to conduct fire behavior modeling for estimating fire size, spread direction, fire intensity and calculation of burn probabilities (Finney 2002, 2006). Through the Web GIS interface, AEGIS will deliver fire behavior estimations, fire danger maps, current and forecasted weather data and fire management data in a timely manner and without devastating delays.

Study areas

AEGIS is currently under development and will be applied in seven different study areas with high-hazard, high-value and high-use forest and other multi-purpose lands. Each area covers a mix of different conditions either in socioeconomic situations (i.e. rural/ urban and interface areas, changes in population size/ density, etc.) or in environmental factors (i.e. climate, vegetation, topography, geographical distribution, etc.). By applying results and outcomes of this research, knowledge is gained and tools are developed that may allow us to apply the system to the rest of Greece or elsewhere with minimal efforts and resources in the future. The study areas are (Figure 1):

1. The island of Rhodes located in the southeastern Aegean Sea of Greece covers an area of 1400 km^2 (with 117000 permanent residents; i.e. 83 persons per km^2). There is an extreme human pressure on the island's ecosystems due to the increased tourism and the resulting urban expansion into the wildland-urban interface to cover housing and recreational needs.

2. The island of Lesvos (with 90000 permanent residents; i.e. 55 persons per km^2) located in the northeastern Aegean Sea of Greece covers an area of 1636 km^2. Lesvos encompasses high fire-prone and fire risk ecosystems of Greece. Pine forests and olive groves dominate almost on half of the island's area, making it one of the most tree-covered

islands of Greece.

3. Chalkidiki, which is a three-pronged peninsula located centrally in the region of Macedonia, covers an area of 2886 km^2 (with 80000 permanent residents; 28 persons per km^2). The whole region is heavily wooded with pines and olive trees, and while there are vineyards and fertile farmlands inland, there are no regular rivers flowing all year long.

4. West Attica, located in central Greece, close to the metropolitan area of Athens covers an area of 1060 km^2 (with 151038 permanent residents; 143 persons per km^2). The area is affected by large wildfires and is under continuous pressure and threat. In 28/6/2007, the worst fire event of the past two centuries devastated over 3633 hectares, 2180 of which were forested areas with true-fir trees.

5. The area of Chania (with 156371 permanent residents; i.e. 66 persons per km^2) is located in the western part of Crete Island, with a total area of 2375 km^2 of which 1476 km^2 are mountainous areas. The ever-increasing tourist pressure of the area has increased its vulnerability and fire events do have devastating results on nature, society and the economy.

6. Messenia, located at the southwest edge of Peloponnesus with a total area of 2991 km^2 (176876 permanent residents; i.e. 59 persons per km^2). During the summer of 2007, devastating forest fires affected a big portion of Peloponnesus including Messenia.

7. The area of Kastoria, located at the northwest part of Macedonia, with a total area of 1720 km^2 (53483 permanent residents; i.e. 31 persons per km^2). Climate change has lead to increased fire activity, even in high mountainous areas such as Grammos, where fire has always been a low frequency natural disaster but with high intensity; within this scope, our proposed management tools may also facilitate the ecological research of these very important fire regimes in the area.

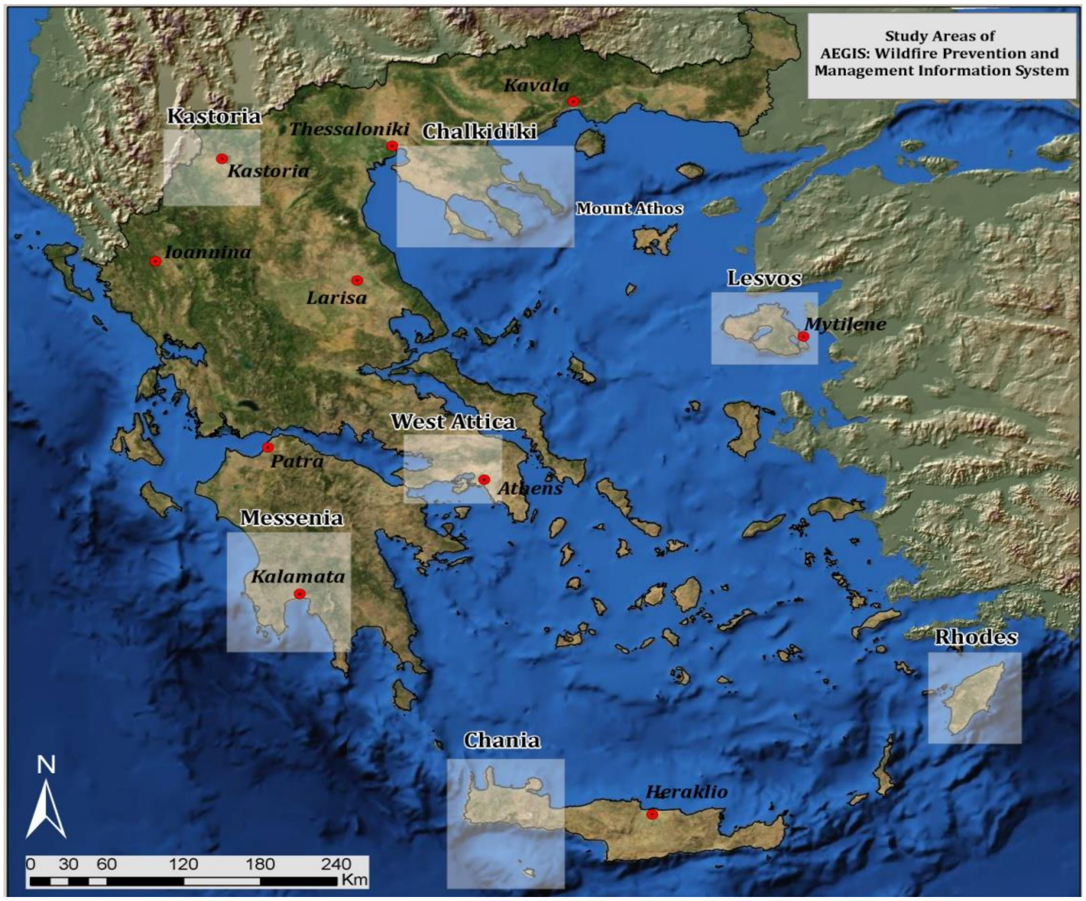


Figure 1: The seven study areas of AEGIS in Greece

Conceptual design of AEGIS

For fire danger calculation and fire behavior modeling, the principles of cloud computing will be followed. Cloud computing enables the users to harness abstracted and virtualized resources, and permit computations over huge amount of information without having their own processing power (Bhat *et al*. 2011). The National Institute of Standards and Technology (NIST) (Mell and Grance 2009) defines cloud computing as "...a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g. networks, servers, storage, applications and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction." The Cloud offers flexible configurations that allow increasing or decreasing the occupied hardware resources dynamically, depending on the real-time demands of hosted applications.

Cloud computing will perfectly fit into the needs of the AEGIS application because of the large amount of data and the complexity of the processing. Taking advantage of the Cloud's ability to increase/decrease the number of available virtual machines (VMs) on demand, end users will be charged only for their consumed processing time and only during the actual wildfire confrontation period.

AEGIS will utilize the public cloud of Windows Azure, based on knowledge gained from participation in the EU-funded research project VENUS-C (Virtual multidisciplinary environments using Cloud infrastructures[1]). VENUS-C developed and deployed a cloud computing service for research and industry communities in Europe by offering an industrial-quality service-oriented platform based on virtualization technologies. The programming model of Generic Worker (Simmhan *et al*. 2010) will be utilized for executing tasks in the Cloud's VMs machines and storing the output results in Cloud's storage containers. End users will consume the cloud resources through the web interface of the application (Figure 2).

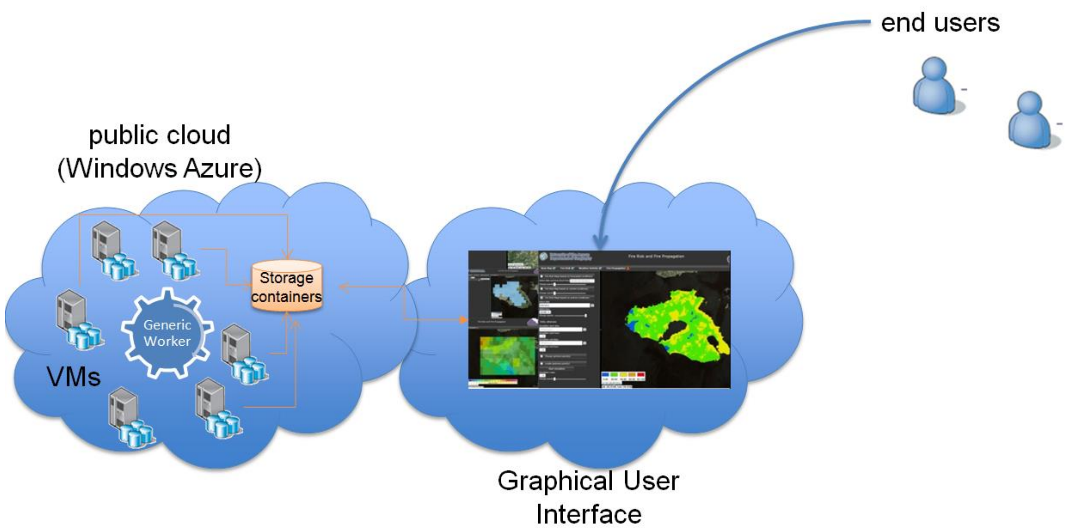


Figure 2: Conceptual approach of task execution in the Cloud

Fire danger maps based on five-day forecasted weather data will be calculated for every study area in a time interval of one hour, once per day. The danger map portrays the geographical probability of a new fire ignition and its expected impacts. Artificial Neural Networks are used for the mathematical modeling of these complex phenomena (Vasilakos *et al*. 2007, 2009). The number of available virtual machines will be increased when new forecast weather data are available (i.e. every morning at a predefined time). After scaling up, every virtual machine will download external data (i.e. real time weather for a specific hour of the next five days data), internal data (i.e. static data stored in the Cloud such as topography, vegetation, fuel types and socioeconomic inputs) and generate the corresponding fire danger map. Furthermore, weather prediction maps of wind fields, air and soil moisture and temperatures, cloud cover, etc. will also be calculated and visualized. The weather prediction maps will be prepared with the operational use of the NonHydrostatic SKIRON/Eta Modeling System (SKIRON) from the Atmospheric Modeling and Weather Forecasting Group (AM&WFG) of the Department of Physics, University of Athens. SKIRON is a state-of-the-art integrated limited area modeling system developed from AM&WFG (Janjic 1994, Kallos *et al*. 1997).

Execution will run in the Cloud by assigning a task to a specific virtual machine (Figure 3). Following job execution, the deployment will be automatically scaled down. After the map creation, users will view the map of interest by selecting the corresponding date and time through the graphical interface of AEGIS.

[1] www.venus-c.eu

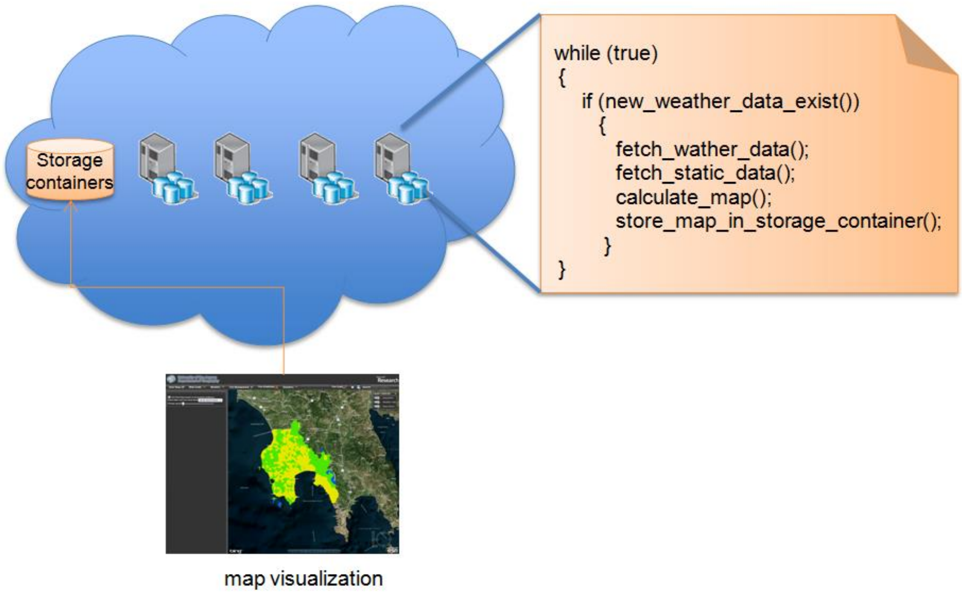


Figure 3: Fire danger computation in the Cloud

Fire behavior modeling in AEGIS is to be conducted by utilizing the MTT algorithm. MTT computes potential fire behavior characteristics (spread rate, fireline intensity, time of arrival, flow paths, etc.) for a single fire, and burn probabilities/ flame length for the entire landscape from several fires based on weather and fuel moisture scenarios. The fire perimeters created by MTT are similar to wave-front expansion (Richards 1990, Finney 2002), but they are mathematically and computationally more efficient. Holding all environmental conditions constant, the MTT algorithm searches for the fastest path of fire spread along straight-line transects connected by nodes (cell corners) (Finney 2006) and it exposes the effects of topography and arrangement of fuels on fire growth (Ager *et al*. 2007).

MTT has the advantage of producing burn probabilities of the entire study area by simulating thousand of potential fires that could burn throughout the area. It permits Monte Carlo simulations of many fires (i.e. more than 100000 fires), to evaluate burn probability and fire intensity for very large (e.g. more than two million ha) landscapes (Ager and Finney 2009). Burn probability is an estimate of the likelihood of a pixel burning given a single random ignition under burn conditions in the simulation. Burn probability modeling represents a major advancement in wildfire behavior modeling compared to previous methods, such as those where fire likelihood was quantified with relatively few predetermined ignition locations (i.e. fewer than 10). As a result, the product of this process is the burn probabilities map that reveals which areas are more susceptible to encounter a fire event and which are more fireproof.

Initial MTT simulations have been executed in a 4-core PC with eight threads and six GB RAM (i7 CPU 2.67 GHz). These tests revealed that the execution time for a simulation based on an Ignition Probability Grid (100000 ignition points) took approximately 48 hours to be completed, while for randomly located ignitions the execution took about 24 hours to be finished. The time needed to run an execution reveals the need for a parallel processing approach to minimize the processing time and to make the results available on a timely manner.

To calculate the burn probabilities for the entire landscape, partitioning of the fire simulations will be applied by running in parallel several MTT simulations in the Cloud. By applying MTT simulations in the Cloud, the execution time is expected to reduce significantly.

Each simulation will be running in a different virtual machine with a fraction of the total targeted number of fires and thus create an intermediate burn probabilities map. For example, if the targeted total number of simulations is 1000 and the available VMs are 10, then every VM will have its own dataset and will execute 100 fire simulations. When all simulations are finished, the final burn probability map will be composed by merging all intermediate results into one of the available VMs (Figure 4).

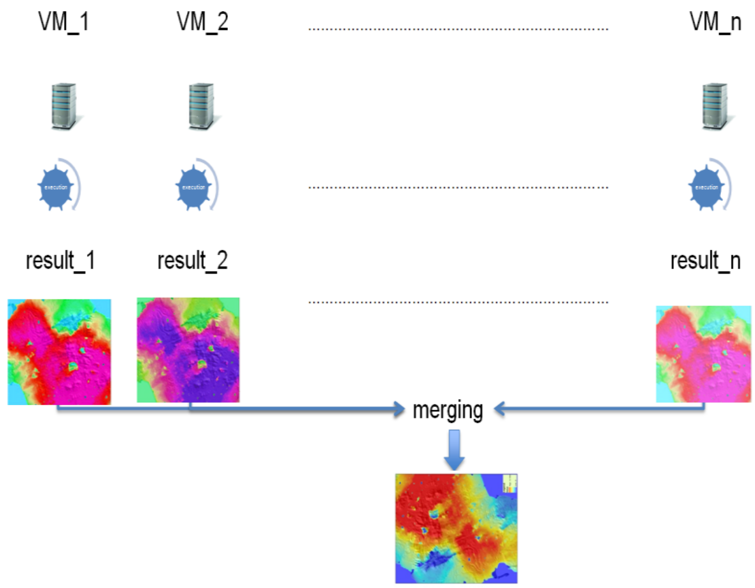


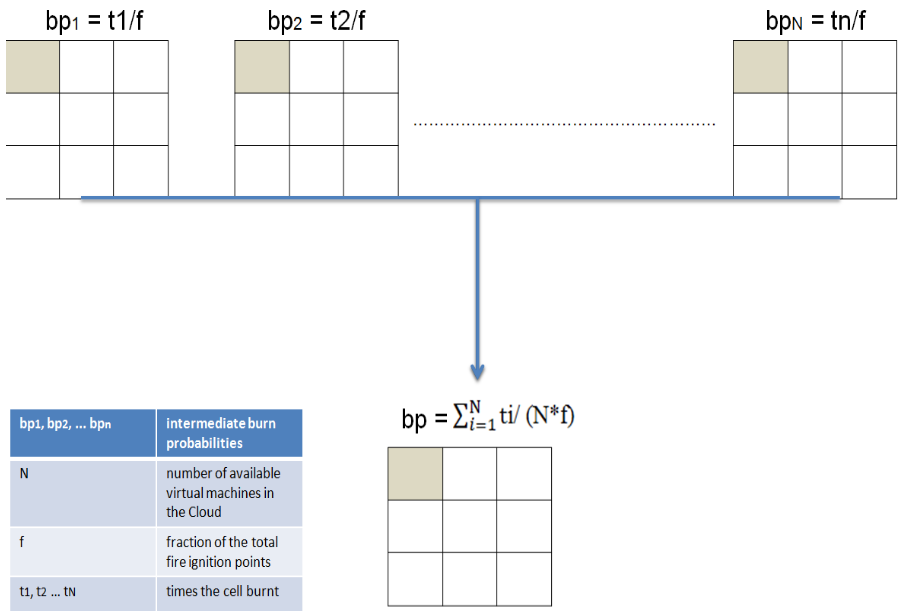
Figure 4: MTT decomposition in the Cloud

The value of each cell in the final map will be evaluated by aggregating all values of the intermediate burn probabilities. Let us assume N virtual machines in the Cloud will be utilized. Then, each intermediate map is created by giving a fraction "**f**" of the total fire ignition points where "f" times "N**"** equals the total number of fire ignition points. Suppose the top-left cell of the first intermediate map has been burned **t1** times. In a similar way, suppose the same cell of the second map has been burned **t2** times, etc. Then, each intermediate burn probability of this pixel would be (Figure 5):

$$bp_1 = t1/f \quad (1)$$
$$bp_2 = t2/f \quad (2)$$
$$\ldots$$
$$bp_N = tN/f \quad (3)$$

And the burn probability of the final (i.e. merged map) would be:

$$bp = (t1+t2+\ldots+tN) / (f+f+..f) = \sum_{i=1}^{N} ti \;/\; (N*f) \quad (4)$$



bp1, bp2, ... bpn	intermediate burn probabilities
N	number of available virtual machines in the Cloud
f	fraction of the total fire ignition points
t1, t2 ... tN	times the cell burnt
bp	final burn probability

Figure 5: Calculating the burn probabilities of the intermediate and final maps

Services and data provided by AEGIS will be accessible through a web-based front end, eliminating the need to install special desktop software. This will cut down on client deployment time and costs to zero, and will enable any authorized user to immediately access the platform from anywhere in the world. Users will have the ability, without the requirement of knowing the handling of complicated GIS applications, to utilize the capabilities of the system. The fire danger and behavior prediction data, along with a plethora of other information spanning from roads, location of water tanks, the positioning of aircrafts and vehicles, images from detection cameras, vegetation types, terrain and weather data will be visualized over web satellite images from Microsoft Bing Maps[2], enabling firefighters in control centers or *in-situ* to manage more effectively forest fires and deal with any other emergency situations that may arise.

Bing Maps will be the predefined background mapping scheme, providing high resolution satellite images and detailed thematic maps with annotations and road network information. Aerial orthophotos, topographic/ thematic maps, satellite images and land use / land cover types from other sources/ independent providers can also be selected and displayed at will. Apart from background layer selection, users will have access on fire information that may aid in forest fire suppression efforts. This information includes the road network, water tanks, pumping stations, fire hydrants, fire watch outlooks, monuments, weather stations, helipads, gas stations, landfills, evacuation sites and fire fighting vehicles patrol sites.

Several tools and services such as fleet tracking, live camera image streams, geo-processing tools and GeoRSS feeds is planned to be integrated. Coordinates of fire service vehicles and patrol light-aircrafts can be located online and in real-time with Global Positioning System (GPS) tracking devices. Firefighting officers can locate and track online the real positions of vehicles and airplanes during a fire event to manage and coordinate them.

[2] http://www.bing.com/maps

Besides the real-time positioning of the firefighting forces, users will be able to ask for the closest fire suppression facilities such as water tanks from any spot on the case study area. "Closest route" queries regarding the location of closest water tanks, fire hydrants and pumping stations will also be supported, as well as the analysis of the shortest distance among locations on the map and finding the drive time distances from a site.

Discussion and Conclusion

This article describes the conceptual approach and design of AEGIS, a state-of-the-art cloud-based Web GIS system that will integrate fire danger rating and fire growth modeling schemes. By using and testing the innovative proposed fire behavior algorithms, maps will be produced on demand and real-time to graphically represent the spread and intensity of a forest fire at different times and places, including burn probabilities and fire effects.

The AEGIS application will offer services beyond simple coordination of emergency activities. Remote automatic weather stations and a weather forecasting system based on the SKIRON weather model will provide crucial data needed for fire prevention and early warning. "Shortest routes" queries will provide in real-time the sites of the closest water tanks, pumping stations and fire hydrants. Fire management professionals will be able to locate, in real-time, the coordinates of a fire patrol aircraft and a fire vehicle. Web cameras will augment enhance the capabilities of AEGIS by transmitting images of high-risk areas into the system, while live feeds will further enhance the communication between end users.

Geographical representation of fire danger potential and identification of high-risk areas is to be provided daily, based on cloud computing techniques. With the AEGIS innovative and advanced programming tools, firefighting personnel, emergency crews and other authorities will be able to design an operational plan to encompass the forest fire, pinpointing the best ways to put it out with new levels of precision. Regarding the forecasted fire danger, maps of ignition risk, values at risk/vulnerability and burn probabilities will be provided. Fire behavior modeling will be conducted by utilizing the MTT algorithm of the FlamMap, which is a fire behavior mapping and analysis program that computes potential fire behavior characteristics (spread rate, flame length, fireline intensity, etc.) over an entire landscape for constant weather and fuel moisture conditions.

One of the compelling advantages of AEGIS lies in leveraging GIS capabilities without the need for extensive training on commercial or complicated GIS applications. The Cloud will provide the necessary processing power and storage that is required. Thus, end users will not need to possess any huge processing power or storage capabilities locally. From the end-user point of view, all that is needed to access the tool will be a standard computer or laptop, an Internet connection and a web browser. All of the application's data will be stored in the Cloud, while the visualization of the outputs is to be achieved through a Silverlight-based graphical interface. The instant and prompt availability of processing power along with the cost effectiveness, reliability and scalability of the Cloud will be key benefits of the application. The sharing of resources among fire agencies will lead to reduced costs, higher efficiency and effectiveness in fire confrontation.

By applying the results and outcomes of this research, knowledge gained and tools developed may allow application of the system into more geographical areas of Greece or countries and in larger spatial contexts with minimal effort and resources in the future; of course, under the assumption that the necessary input databases and services for these regions will be provided.

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