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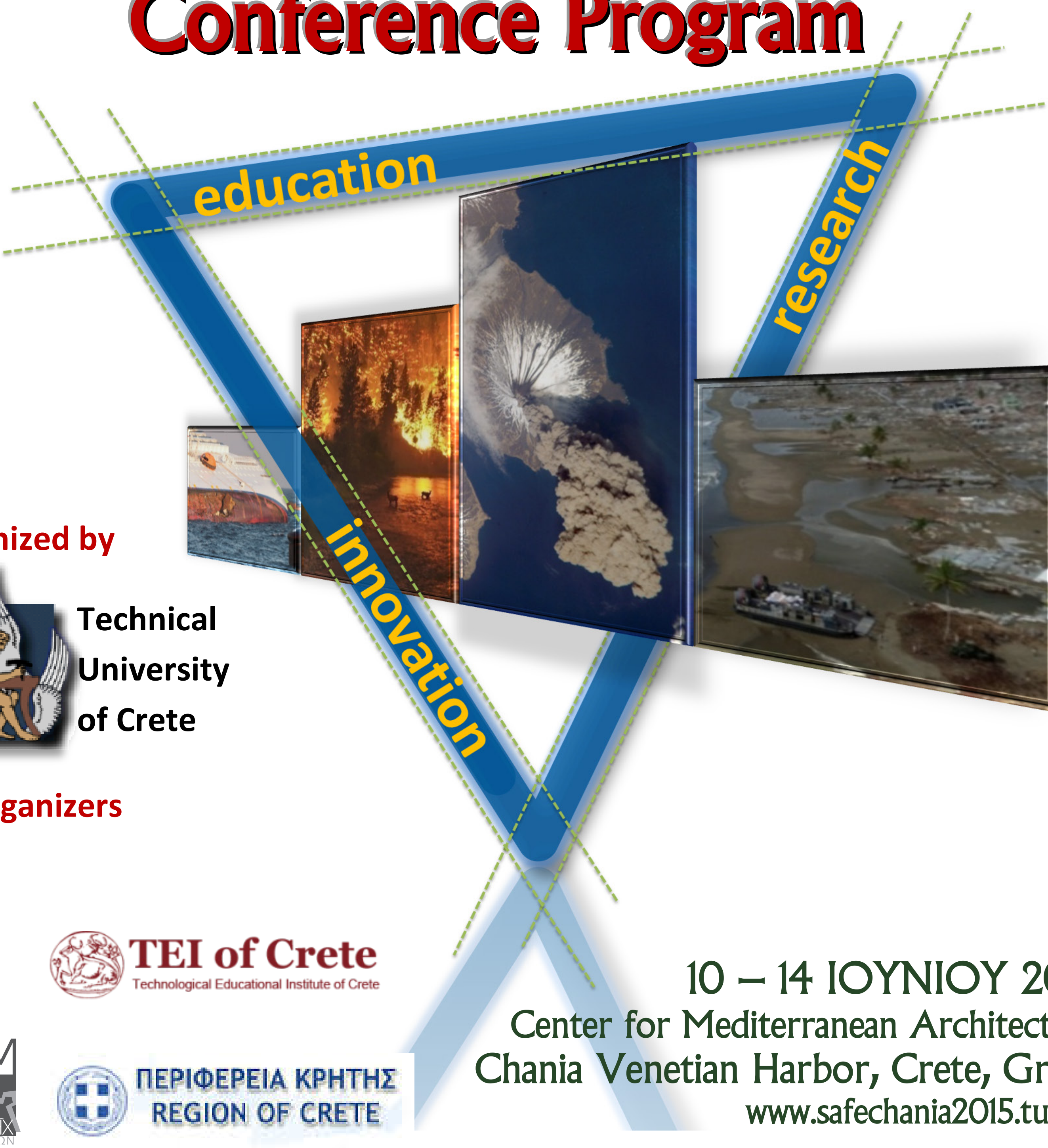

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AEGIS: Wildfire Web Geographic Information System

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ABSTRACT

A Web-GIS wildfire prevention and management information system (AEGIS) was developed as a cost effective and easy-to-use forest fire platform (http://aegis.aegean.gr). The AEGIS platform is to assist on early fire warning, fire planning, fire control and coordination of firefighting forces by providing access to information that are essential for wildfire management. Detailed land use/ land cover maps were provided by combining field inventory data with high resolution multispectral satellite images (RapidEye) and other techniques. Several databases were created with spatial and non-spatial data to support key system functionalities. Artificial neural networks were utilized for wildfire ignition risk assessment based on various parameters, training methods, activation functions, pre-processing methods and network structures. The system also incorporates weather measurements from remote automatic weather stations and weather prediction maps. Furthermore, the utilization of the Minimum Travel Time algorithm acts as a powerful fire behavior prediction system. End users should provide a minimum amount of inputs such as fire duration, ignition point and weather information to conduct a fire simulation. AEGIS offers three types of simulations; i.e. single-fire propagations, conditional probabilities and at landscape level, respectively, similarly to the FlamMap fire behavior modeling software. The structure of the algorithms relied on parallel processing techniques (High Performance Computing and Cloud Computing) that ensures both computational power and speed. All AEGIS functionalities are accessible to the end users through a web-based graphical user interface. An innovative mobile application, called AEGIS App acts as a complementary tool to the web-based version of the system.

Keywords: Fire Danger, Fire Behavior, Decision Support Systems (DSS), Cloud Computing, Web-GIS, ArcGIS Server, FlamMap

INTRODUCTION

Wildfires in Greece constitute the most devastating natural hazards, along with floods and earthquakes. Although many wildfire management systems have been developed in Europe, the current Greek firefighting strategy does not integrate newer geospatial tools and decision support systems that are being implemented as part of strategic and tactical suppression systems used elsewhere (Nivolianitou and Synodinou 2011). The AEGIS system was designed and implemented to fill this gap and delivers state-of-the-art fire management services using Web-based Geographic Information System and wildfire modeling. It was been developed and tested in seven study areas across Greece (Rhodes Island, Lesvos Island, Halkidiki, Kastoria, West Attica, Messenia and Chania). Each test area covered a mix of different socioeconomic (e.g. rural and urban interface areas, changes in population size and density, fire history, land management practices etc.) and environmental conditions (e.g. climate, vegetation, topography etc.).

The system is structured on four interrelated and interconnected subsystems. The first one consists of a Geographic Database (GDB) that contains all available wildfire management spatial information. The second subsystem is a fire ignition prediction model that employs artificial neural networks to identify the spatial pattern of wildfire ignitions. The third subsystem uses a fire behavior model, based on the Minimum Travel Time (MTT) algorithm (Finney 2002) to simulate wildfires. The fourth subsystem uses web-based interface and geospatial mapping services to provide a streamlined end-user interface, designed specifically for civil protection authorities, that eliminates the need for specialized software installation. In this paper we describe the individual subsystems and the overall system functionality that resulted from the three-year research effort to build and test the system.

GEOGRAPHIC DATABASES

One of the main objectives of AEGIS was the collection of spatial and non-spatial data, to develop and organize a comprehensive GDB for each study area. Data were collected from various public and other agencies, including road networks, vegetation types, fuel models, hydrant locations, topographic data, firefighting related data, infrastructures, urban areas, forest management data, historic weather data etc. Additionally, field inventories were conducted in each of the seven study areas to collect data on vegetation type, stand height, canopy base height and fuel models. Retrieved data were edited, updated or recreated, supplemented by metadata that comply with the INSPIRE standards. For each GDB, conceptually similar data were organized in 11 distinct groups (i.e. geophysical, forestry/ vegetation, fire history, administration, high risk areas, networks and infrastructure, water sources, high protection sites, annotations, firefighting infrastructure, and raster data and maps) using the ArcGIS software.

Detailed land use and cover type maps were created based on innovative image processing methodologies with high-resolution multispectral RapidEye satellite images (of 5 m resolution). Auxiliary data, such as the vegetation classification system CORINE 2000, field derived data and forestry data were used during this process. To account for seasonal effects on vegetation, two image mosaics of each study area were used for two time periods of the same reference year. The satellite image processing was conducted in three stages: preprocessing, dividing each study area into homogenous physiographic zones; classification, with a fuzzy set technique and application of a segmentation algorithm; post-classification, applying convolution filters for image smoothing. Finally, corrections were applied on the results (vector files) by visual interpretation, digitization and cover type characterization over aerial orthophotos. Figure 1 exemplifies the derived land cover types map of one of the study areas.

WILDFIRE IGNITION RISK ESTIMATION

Within the AEGIS project, a new methodology for wildfire ignition risk estimation was developed based on previous research experience (Kalabokidis *et al*. 2012, Vasilakos *et al*. 2007, Vasilakos *et al*. 2012). Artificial neural networks techniques were further exploited based on three different methodologies: i.e. Back Propagation, Kohonen and Radial Basis Functions neural networks (Tsekouras *et al*. 2015). The back propagation method proved to perform better compared to the other two. As a result, this method was selected and applied for operational use. Development of the final algorithm was based on trial and error techniques. Three different activation functions were tested for transferring the signal between input and hidden nodes; i.e. logistic sigmoid, hyperbolic tangent sigmoid and linear functions. The input parameters were used either unprocessed or normalized. Finally, the training process was controlled by the early stopping method, where the number of validation samples and the maximum number of training epochs were monitored.

For each possible combination of the above parameters, a back propagation neural network was developed with one hidden layer of 5 to 20 processing nodes. Eighty percent of the sample was used for training, while the rest was utilized during the validation stage. The selection of these samples was randomized during the initialization stage. Each network was trained for 10 initializations; therefore, 1,008 networks were developed for each study area. Based on the above results, the best performing networks of Mean Square Error of the validation dataset was saved for each area and integrated into the platform to be used for the cartographic representation of wildfire risk (Figure 2). Results revealed that:

- Each study area uses its own neural network, which means that the spatial wildfire ignition pattern is different among them.
- Neural networks of all study areas showed remarkable performance, except the network of Rhodes Island that its spatial wildfire ignition pattern is not distinctive.
- Best performance was observed in West Attica.

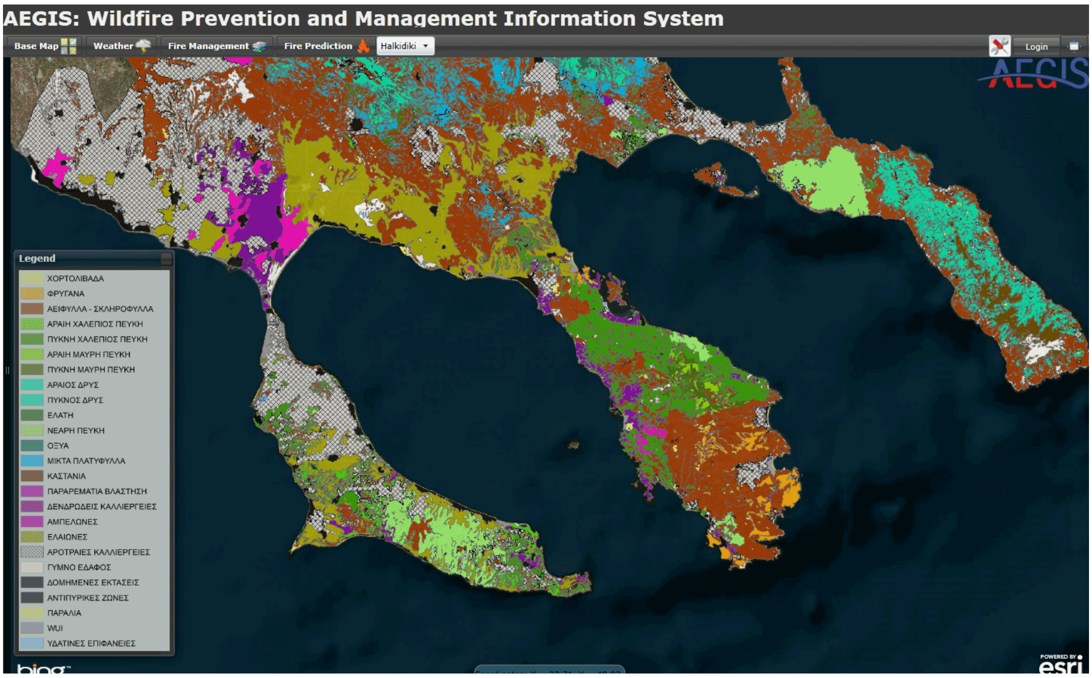

Figure 1: Land cover types map of Halkidiki study area in N. Greece, derived from RapidEye satellite image processing as viewed within the AEGIS interface

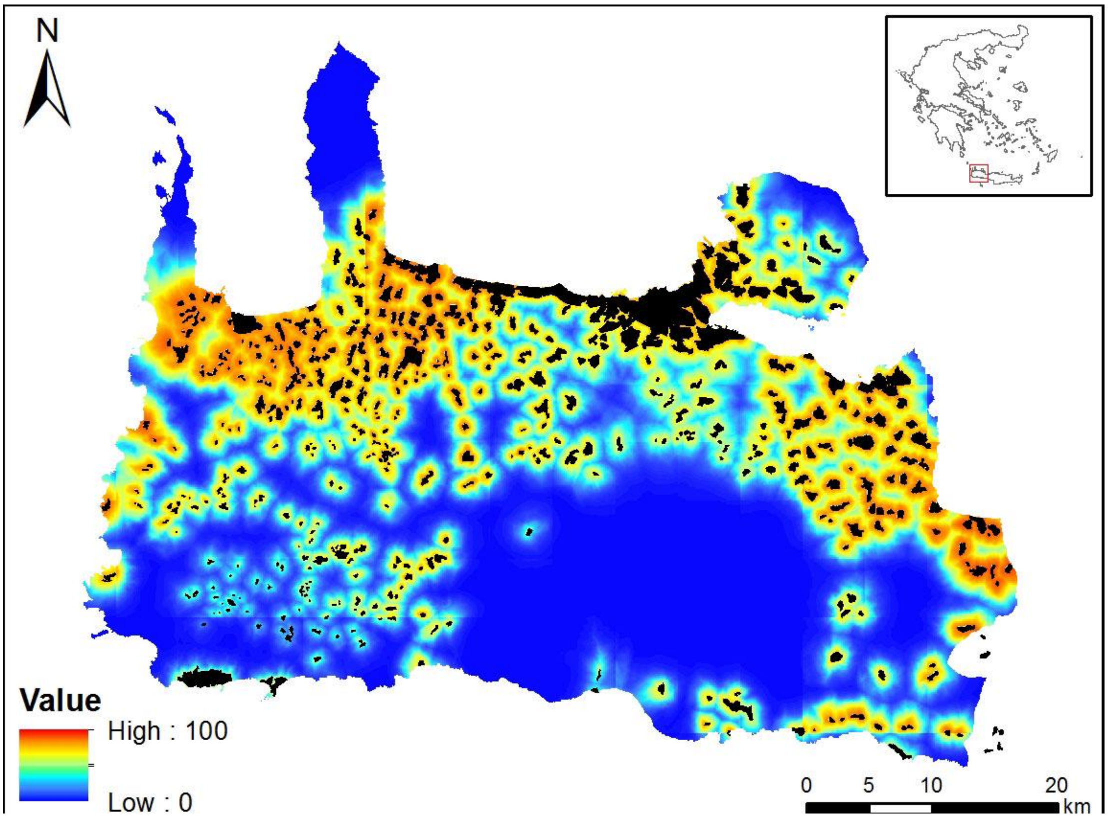

Figure 2: Wildfire ignition risk map (per cent probability) of Chania study area in W. Crete Island, Greece, for an example date and time as generated by the ignition submodel in the AEGIS system

FIRE BEHAVIOR MODELING

AEGIS provides an easy-to-use wildfire behavior modeling scheme that utilizes the MTT algorithm as a cell-based tool for fire behavior predictions, fuel treatments and fire danger estimation in conjunction with FlamMap v.5 modeling capabilities (Finney 2006). The MTT algorithm is applied in strategic and tactical fire management planning in USA (Ager *et al.* 2012), and integrated into the Wildland Fire Decision Support System (WFDSS) (Pence and Zimmerman 2011). Holding fire weather 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 exposes the effects of topography and arrangement of fuels on fire growth (Ager *et al.* 2012). The MTT algorithm can be used to compute the potential short-term fire behavior characteristics (rate of spread, fireline intensity, time of arrival, flow paths etc.) for a single fire or simulate many fires to generate conditional burn probabilities and flame length using Monte Carlo stochastic simulations, where fire weather and fuel moisture information varies among the simulated fires. Additional outputs are produced for the entire landscape (flame length, rate of spread, fireline intensity, heat per unit area, crown fire activity, spread vectors etc.).

In the AEGIS system, users provide inputs on the wildfire ignition point (by clicking on the map or by providing coordinates), the fire duration (<=6 hours), the wind speed and wind direction as derived from a remote automatic weather station (RAWS) and a fuel moisture scenario. If the user does not define a RAWS then the system automatically finds the closest one to the fire ignition. When a fire simulation is initiated by the user, MTT is executed and the necessary input parameters are read from a configuration file generated at runtime. Upon the completion of execution, several output files are generated either in raster or vector format. Finally, ArcGIS Server mapping services retrieve information written to geodatabase feature classes that provide spatial depictions of the fire simulation (Figure 3).

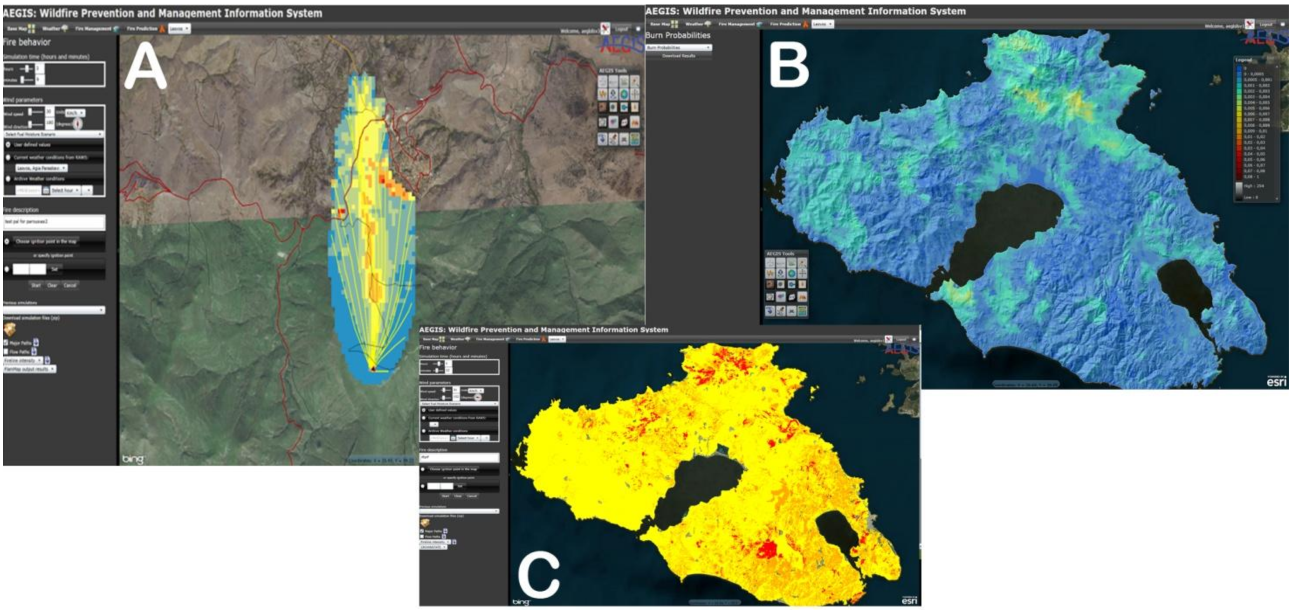

Figure 3: Example outputs from the AEGIS fire simulation system for the island of Lesvos, NE Aegean Sea, Greece: A) Predicted fire perimeter showing fireline intensity; B) Seasonal fire behavior as predicted by burn probability; C) Landscape level predicted crown fire activity

AEGIS PLATFORM

AEGIS is implemented within a web-based interface that provides direct access to required spatial data fire behavior prediction tools. The web platform uses ArcGIS API for Silverlight that provides for integration of geographic analytical services (geo-processing) and data mapping (cartographic services), supported by a geographic server (ArcGIS Server) and the Bing Maps web mapping service. The Silverlight application is hosted as an Internet Information Services (IIS) application. The IIS Server also hosts the meteorological data management system that is responsible for the retrieval, manipulation and storing of all weather data feeds from the interconnected RAWS in a relational database. Tools such as routing between waypoints can help end users to design a more effective operational response and forest fire management plan (Figure 4).

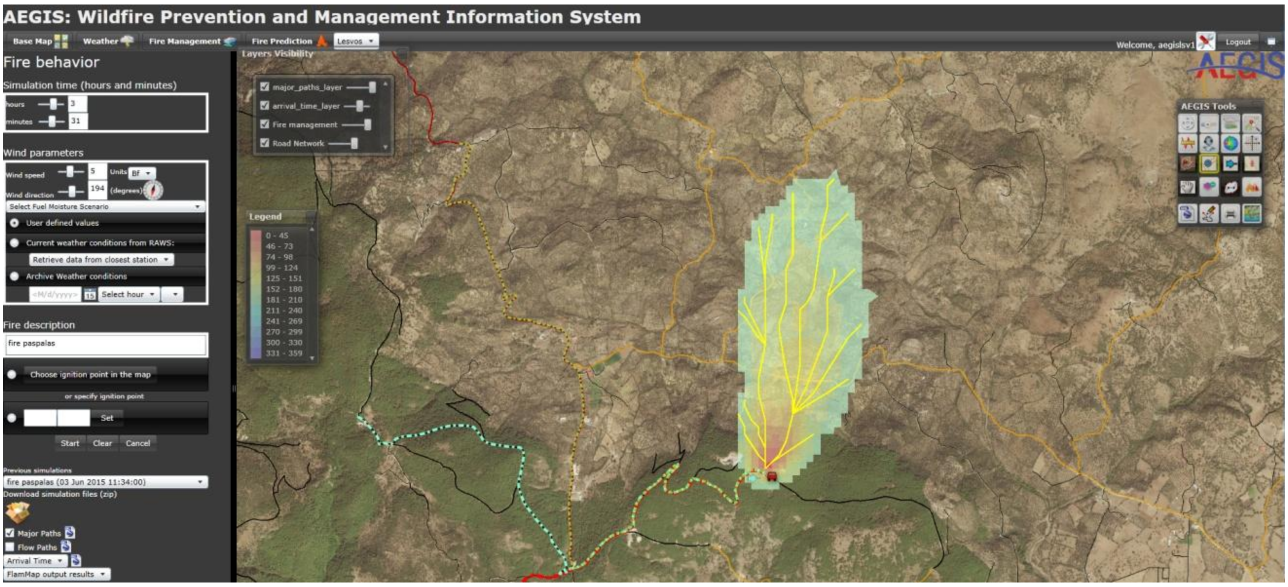

Figure 4: Snapshot from a fire behavior simulation over the AEGIS platform, supplemented by auxiliary fire management data

The system can be accessed through a smartphone application for Windows Phones (AEGIS App) to provide mobile functionality. The mobile application has been designed to work in cooperation with the web-based platform of AEGIS, allowing sharing information, data and functionalities between them. To the best of our knowledge, it is the first wildfire management application for native Windows Phone devices. Upon opening of the AEGIS App, the current end-user location is tracked (received from the GPS sensor of the device) and visualized as a fire vehicle symbol on top of the background mapping schemes (Bing Maps or Open Street Maps). Below the map, several options and icons exist that provide access to different functionalities. An innovative feature of AEGIS App is the support of these tasks by a new digital assistant for artificial intelligence named Cortana (developed by Microsoft for Windows Phone devices), that allows information utilization through voice commands (Figure 5).

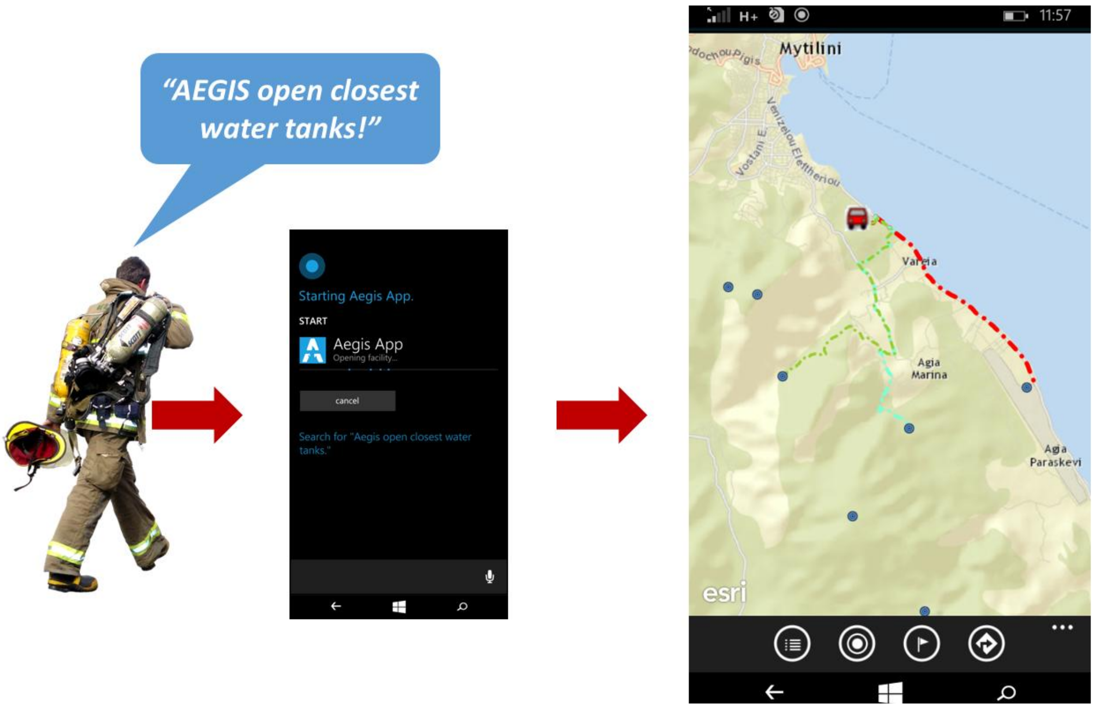

Figure 5: A screen capture of the AEGIS App for Windows Phones

CONCLUSIONS

This paper presents the core functionality of the AEGIS system that resulted from a three-year development and testing period. The AEGIS web platform offers decision support services beyond the coordination of emergency activities. Updated vegetation maps, created by combining field data and remote sensing products are used for fire behavior modeling and ignition risk assessment. Artificial neural networks were used for the mathematical modeling of the fire risk. The three different methodologies used showed remarkable performance in the identification of different spatial patterns of wildfire risk. The sensitivity analysis of the trained networks showed that wildfire ignitions for each study area are influenced by specific parameters. The fire behavior system, incorporated in the platform based on the MTT algorithm, can produce dependable simulations during the first six hours of a fire ignition. All calculations are performed in a parallel processing environment, combining the technology of Microsoft Azure Cloud Computing (Kalabokidis *et al*. 2014) and High Performance Computing (Kalabokidis *et al*. 2013). The combination of these computing resources results in reduced implementation costs and times, since the fire emergency authorities are to be charged only for their consumed processing time (e.g. during the active fire season).

The combination of the web-based version of the AEGIS platform with the AEGIS App provides access to key services of fire management and planning, especially to the operational end users at the front line. In case of a fire emergency, end users can utilize the mobile app at the field and the location of the fire is directly transmitted in the GUI of the web platform of AEGIS. In conclusion, the AEGIS platform may potentially support civil protection and fire control services in the organization of innovative wildfire management plans.

ACKNOWLEDGEMENTS

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