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An operational platform for fire danger prevention and monitoring: insights from the OFIDIA2 project

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Abstract

The project OFIDIA2 (Operational FIre Danger preventIon plAtform 2), funded by the Interreg Greece-Italy 2014-2020 Programme, proposed a pragmatic approach to improve the operational capacity of the stakeholders to detect and fight forest wildfires. A data analytics system was designed and implemented within the project to manage, transform, and extract knowledge from heterogenous data sources, through forecasting models such as weather, fire danger, and fire behaviour models, as well as monitoring data from sensors, weather stations, cameras, and drones. Additionally, the project has developed an innovative DSS that provides complete coverage of technical activities to support wildfire hazard management and decision makers in real time.

In this work, we present the OFIDIA2 platform architecture and then we focus on the main findings concerning the component "fire behavior" of the project. Indeed, fires, fuel, topography and weather data were collected from several sources and used to run and calibrate two fire models (FlamMap and Wildfire Analyst) in the project regions. Based on the analyses of recurrent weather conditions leading to large fires, fire metric's maps for prevention and fire-fighting activities were produced. The final information was then included within the DSS to support and improve firefighting and fire management programs.

1. Introduction

Forest fires are a critical problem in Mediterranean regions, especially during summer, threatening ecosystems biodiversity, human life, and high-value assets. High temperatures, strong wind, and low precipitations are the ideal conditions for the occurrence of intense and rapidly spreading fires. In this context, it is of utmost importance to provide fire managers and civil protections with an adequate fire-intelligence system that can provide information to support effective management of wildland fires and decision-making, from the optimization of wildfire prevention and firefighting resources and reducing fire effect impacts on valued resources.

Towards this aim, the project OFIDIA2 (Operational FIre Danger preventIon plAtform 2, https://www.interregofidia.eu/), funded by the Interreg Greece-Italy 2014-2020 Programme, proposed a pragmatic approach to improve the operational capacity of the stakeholders in Apulia (Italy) and Epirus (Greece) regions to detect and fight forest wildfires.

The main goal of OFIDIA2 Project was the development of a software platform for fire danger prevention, able to predict fire risk and danger in case of fire outbreak, based on the constant measurement of several environmental variables detected through appropriate sensors across Apulia and Epirus Regions. The project started in May 2018 and ended in May 2021.

In this short paper, we will present the OFIDIA2 platform architecture and related services (section 2) and then we will focus on the main findings concerning the component “fire behavior” of the project (section 3).

2. OFIDIA2 platform architecture and related services

The project OFIDIA2, based on the results of previous project OFIDIA (Mirto et al., 2015), has implemented a Decision Support System (DSS) for prevention planning and emergency management of forest fire events that incorporates weather data management, fire danger indices, and fire behaviour models, as well as monitoring data from sensors, weather stations, cameras, and drones.

As depicted in Figure 1, the collection, input, storage, management, and analysis of information rely on advanced and automated methodologies using NetCDF (Network Common Data Form) data, digital mapping, and textual data. NetCDF stores multidimensional (variable) scientific data, such as temperature, humidity, pressure, wind speed and direction. The results include i) short-term dynamic fire danger indices developed for improved and realistic prevention and pre-suppression planning; ii) fire behaviour maps to help determine the impact of fire to a considerable extent; iii) an automatic fire detection technology, based on wireless sensors, weather stations, video cameras and drones, successfully tested on several sites.

Additionally, the project has developed an innovative DSS that provides complete coverage of technical activities to support wildfire hazard management and decision makers in real time. The main DSS services are:

- *Forecast Weather maps*: each day an operational chain at the CMCC Supercomputing Center, located in Lecce, produces 72hr forecast data by the WRF meteorological model (Michalakes et al., 2004) with 2x2km resolution. These data are used both for calculating fire danger indices and selecting the fire behaviour maps.
- *Fire Danger indices*: Starting from the WRF data, the maps of three fire danger indices were produced: Canadian, Fosberg and Ichnusa for a time period equal to 72h.
- *Fire Behaviour*: Landscape fire spread and behaviour models have been applied. Two fire simulation models were used for a mean weighted scenario to define the fire weather scenarios and to assess key wildfire characteristics.
- *Dashboard Monitoring*: Regarding sensor monitoring, innovative sensors named Tree Talker Fires send data to a web server every hour. With the same frequency they are downloaded and analyzed at the Supercomputing Center. Data quality and cleaning routines are applied to extract the variables of interest and store them in structured form in the monitoring system. Data are also transferred to the Civil Protection. The variables are displayed in graphs. In the event of an alarm, the system sends an email to the control room manager and commands the cameras to acquire a small piece of video and send it to selected members of the control room.
- *Video cameras*: The system allows monitoring of cameras installed in the forest sites and their geolocation.
- *Historical drone videos*: It is also possible to view the history of the videos acquired with the drones supplied by the Civil Protection.
- *Fleet management*: The fleet management service was born as a support to the group of Civil Protection volunteers. The alarm system implemented in OFIDIA2 allows optimized management of volunteer teams, called teams. Each team is geolocated through our mobile APP. When an alarm occurs, the operator in the control room displays either the single sensor that triggered the alarm or a group of sensors determined by a polygon. Then the operator can see the real position of the teams and select the team that is closest to the site that generated the alarm. Then the system calculates the optimal path that the team must take. The route will be displayed to the team via the mobile App. It is also possible to guarantee the team's interaction with the Control Room operator through a messaging service that remains stored for further analysis.

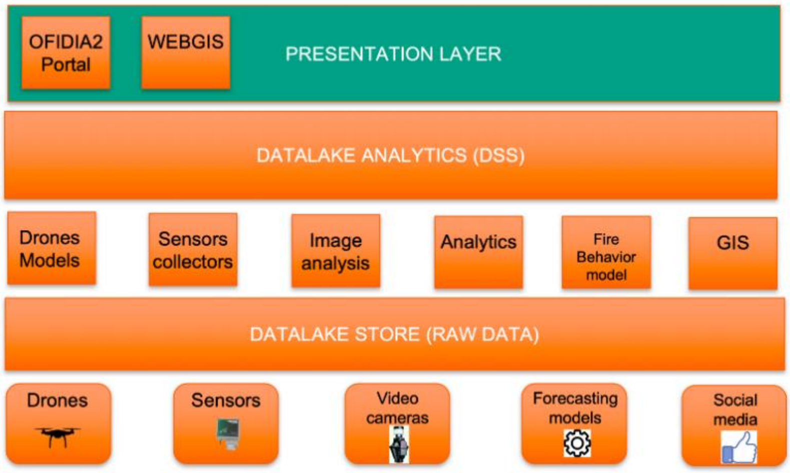

Figure 1- OFIDIA2 architecture

3. Fire behaviour modelling component

In the framework of the "*Fire Behaviour*" DSS service, two fire behaviour modeling tools were run to provide a set of fire behavior characteristics, assessed for a set of fire weather scenarios. This information was then included within the DSS to support and improve firefighting and fire management programs.

3.1. Input data, fire weather scenarios, and fire modelling

We firstly acquired available information on fire ignition for the period 2007-2017 and then the gridded ERA5-Land dataset at 0.1° of resolution through the Copernicus website. A set of multivariate statistical procedures were applied to the database to explore potential associations between fire weather variables and the incidence of large fire events (>100 ha). Clustering technique was applied to weather data looking for groups of observations, evaluating all possible pairs of clusters with the cluster that results in the smallest increase in error sums of squares is used (Everitt and Hothorn, 2011). Thus the parallel coordinate plot (PCP) technique for the visualization of multivariate quantitative data was applied. Finally, to visualize and understand the cluster solution and to highlight an individual observation that represents each cluster, medoids (Kaufman and Rousseeuw, 1990) were calculated to succinctly represent a cluster, also called fire weather scenarios (FWS). Each FWS was made thus of mean wind speed, wind direction, and relative humidity data.To define fuel type and canopy cover layers, the 2012 Corine Land Cover map was reclassified following the methodology in Salis et al. (2013). As a result, 13 fuel types were obtained and associated to the standard or custom fuel models from the original 44 Corine land cover categories present in the study area.

FWS, togheter with information on fire ignition, topography and fuel models, were then used to simulate fire behavior characteristics (e.g., rate of spread, fire intensity, burn probability, fire potential index) through two fire propagation tools, WildFire Analyst (WFA, Monedero et al., 2019; Ramírez et al., 2011) and FlamMap (Finney, 2006). We simulated 36,000 fires (~2 fire per km^2) taking into consideration the historical ignition density of the study area for the period 2007–2017. The simulations were conducted considering constant fuel moisture, wind speed, and wind direction according to the FWS. Fire spread duration was set of 10 h, which is a common average duration of large historical fires in the Mediterranean area. Fire suppression operations as well as barriers to fire spread were not considered.

3.2. Main results

For sake of conciseness, only the results for a mean weighted scenario (i.e. the weighted mean of each single model output according to the relative frequency of each weather scenario) in Apulia region for both simulators WFA and FlamMap are presented here below.

3.2.1. Fire weather scenarios for Apulia region

Analysis of weather data across fire size showed that large fires (>100 ha) mainly occurred under low humidity and high temperatures (Figure 2a). Despite winds from different directions blow in fire days, south west direction at 15 km hr^{-1} (on average) is one the most common situation in the region (Figure 2b). The cluster analysis revealed four wheatear scenarios in which two have low relative wind speed but contrasting directions whereas the other two have higher wind speed and different directions (north and southwest) (Table 1). Spatial analysis of fire weather scenarios showed that the 1st and 4th clusters (i.e. south west winds) mainly occur in the northern and mid provinces (i.e. Foggia, Barletta-Adria-Trani and Bari). Instead, the other climatic clusters are observed across the Apulia region.

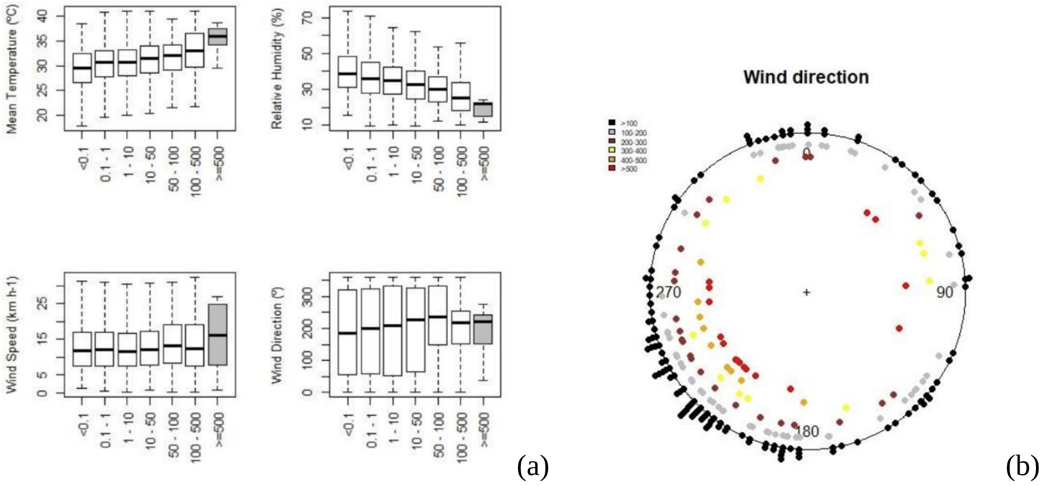

Figure 2 – (a) Distribution of weather variables across fires size categories. (b) Wind direction across fire size categories over 100 ha

Table 1 – FWS according to cluster medoids

Description	*Wind direction (°)*	*Wind speed (km h^{-1})*	*Relative humidity (%)*	*Days (%)*
Sud-ovest calmo	*217*	*6*	*23*	*28*
Est	*72*	*6*	*25*	*19*
Nord	*346*	*18*	*42*	*19*
Sud-ovest forte	*254*	*20*	*19*	*33*

3.2.2. WildFire Analyst simulations

Simulations showed that for all three variables, i.e. flame length, fire intensity and rate of spread, higher values are mainly observed on Foggia, Bari and Taranto provinces. Furthermore, these higher values are mostly observed in the forest protected areas of Gargano, Alta Murgia e Terra delle Gravine (Figure 3). Greatest flame length and fire intensity are projected for shrublands (i.e. maquis) but also in forest of different types whereas fire; rate of spread is projected also higher in maquis and herbaceous vegetation. Fire length and fire intensity are tightly related variables whereas the rate of spread is mostly uncoupled with the previous ones.

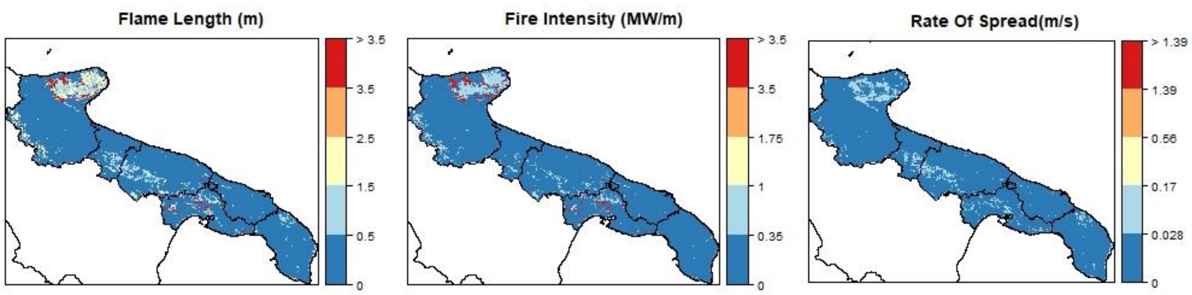

Figure 3 – Flame length (left), fire intensity (center), and rate of spread (right) maps of the Apulia region simulated by WildFire Analyst

3.2.3. FlamMap simulations

FlamMap simulations showed that burning probabilities based on historical fire distribution might be higher in mountain areas of costal Foggia province and along the western axis crossing Barletta-Adria-Trani, Bari and Taranto. Flame length and fire size were also predicted higher over the Gargano in Foggia province. Burn probabilities and fire size showed a quite similar pattern (Figure 4). Based on historical records, burning probabilities, fire size and fire potential index are predicted higher over herbaceous and maquis areas. Instead, conditional flame length might higher in maquis but also in all forest types.

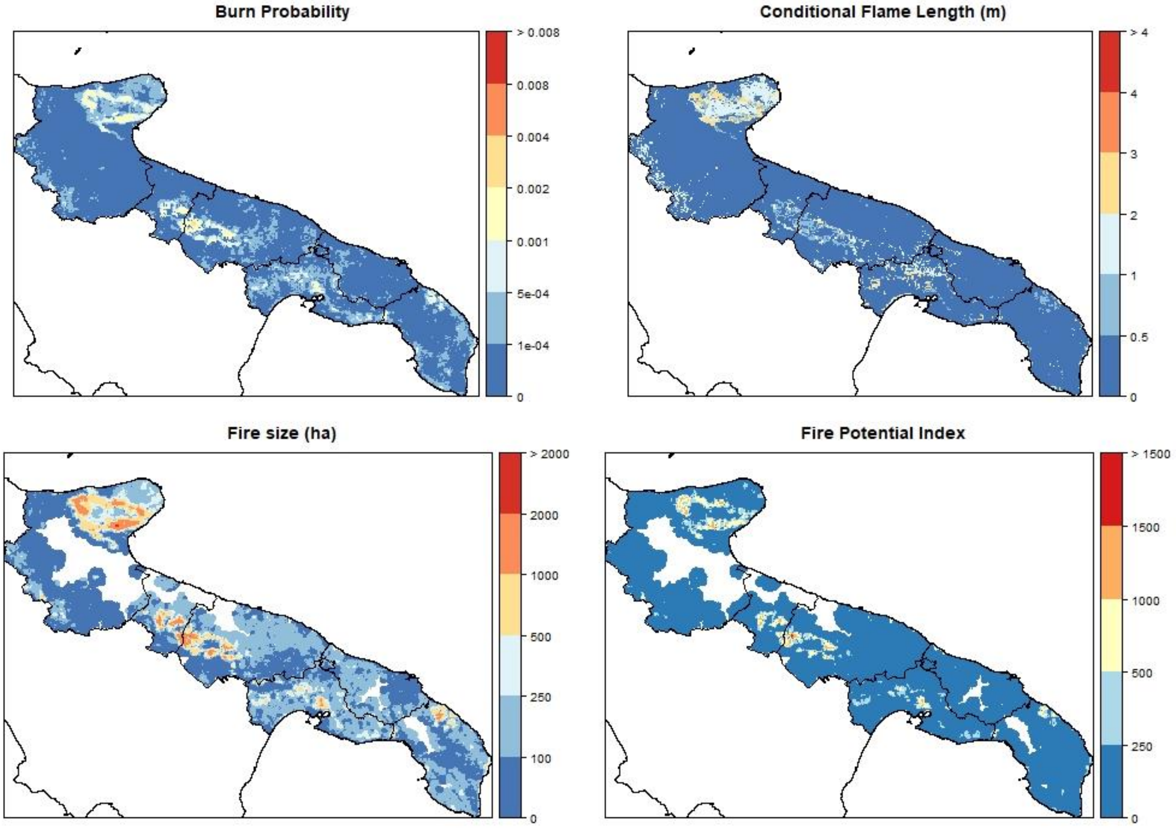

Figure 4 – Burn probability (top left), conditional flame length (top right), fire size (bottom left), and fire potential index (bottom right) maps of the Apulia region simulated by FlamMap

3.3. OFIDIA2 DSS

Finally, fire behaviour characteristic maps for each FWS were imported into OFIDIA2 DSS to allow fast retrieval on user requests. The choice of the FWS depends on the wind speed and direction and relative humidity of that particular day. The variables are request from WRF output. The specific result depends on the definition of the minimum and maximum thresholds (coming from Table 1) that are used to classify a fire day within each FWS. The selected FWS include geotiff images that were imported into a Web GIS (Figure 5). As for the weather forecast of the current day, OFIDIA2 system selects the most appropriate cluster based on the thresholds considered. It is also possible to know the specific value of each variable in the cluster for each latitude and longitude.

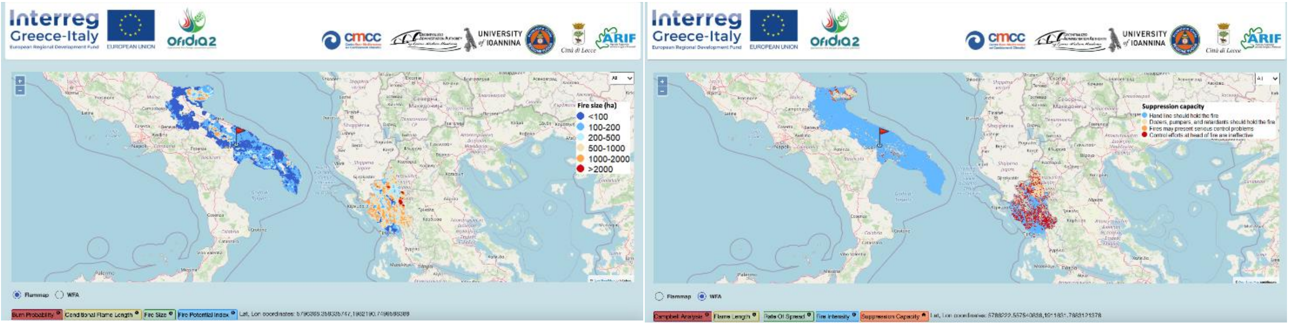

Figure 5 – Examples of the fire behaviour modelling outputs showed by the web GIS of the OFIDIA2 DSS. On the left, fire size calculated by FlamMap; on the right, suppression capacity calculated by WFA.

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