Forest fire simulator system for emergency resources management support

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Abstract— Europe suffers approximately 65,000 fires every year, which burn, on average, half a million hectares of forest areas [1]. The main direct effect of forest fires is the destruction of the natural landscape and the consequent loss of ecosystem service that have drastic economic impact, but mainly and much more important, fires also result in the loss of human lives every year. Although being forest fires a problem present in all EU members, the most affected areas to this hazards are the southern countries due to their climatological conditions. All affected countries invest lots of resources to minimize fire damages, but many times when dealing with large fires, regional and national disaster management units are lack of efficient and reliable tools to help wildfire analysts. In this work, we describe a process to generate on-line wildfire simulations coupled with the regional weather forecast service (Servei Meteorològic de Catalunya , SMC) and the helicopter company (Helipistas S.L) who provides isochronous perimeters of the fire behaviour in a certain moment of the emergency and how both of this data sources feed the inputs for the simulation process.

Index Terms—Forest fire; Dynamic data driven application system; Meteorology ; Models; Helicopter, Simulation

Resumen — Europa sufre aproximadamente 65,000 incendios cada año, de media, medio millón de hectáreas forestales[1]. El principal efecto de los fuegos forestales es la destrucción de la superfície natural y como consecuencia la pérdida del ecosistema y el gran impacto económico, pero principamente y de manera mucho más importante el fuego tambien repercute en la pérdida de vidas humanas año tras año. Los fuegos forestales además de ser un problema para los miembros de la UE, se ven repercutidos, especialmente los paises del sur debido a sus condiciones climatológicas. Todos estos paises afectados invierten gran cantidad de recursos para minimizar estos efectos. Generalmente cuando se trata de grandes incendios forestales, las unidades de mando de estos medios de exinción a nivel regional y nacional se ven necesitados de herramientas eficientes y útiles para el análisis de la predicción del comportamiento de estos grandes incendios forestales. En este trabajo, describimos un sistema de predicción de incendios forestales acoplado con el servicio meteorológicos de catalunya (SMC) y la empresa de helicópteros (Helipistas S.L) los cuales proveen de los perímetros del incendio en un instante de tiempo de la emergencia y cómo estas dos fuentes de datos se anexan al proceso de simulación.

Palabras clave - Incendios forestales; Aplicaciones dirigidas dinamicamente; Meteorología; Modelos; Helicópteros; Simulaciones

Resum — Europa pateix aproximadament 65,000 incendis cada any, de mitja, cada mig-milió d'hectàrees forestals[1]. El principal efecte dels focs forestals es la destrucció de la superfície natural i com a conseqüència la pèrdua de l'ecosistema i el gran impacte econòmic, però principalment i de manera molt més important el foc, també, repercuteix en la pèrdua de vides humanes any rere any. Els focs forestals a més a més de representar un problema pels països membres de la UE, es veuen afectats els països del Sud degut a les seves condicions climatològiques. Tots aquests països afectats inverteixen grans quantitat de recursos per a minimitzar aquests efectes. Generalment quan es tracta de grans incendis forestals, les unitats de comandament d'aquests medis d'extinció a nivell regional i nacional es veuen necessitats d'eines útils i eficients per a l'anàlisis de la predicció en el comportament dels grans incendis forestals. En aquest treball, descrivim un sistema de predicció d'incendis forestals acoblat amb el servei meteorològic de Catalunya (SMC) i l'empresa d'helicòpters (Helipistas S.L) els quals proveïxen dels perímetres de l'incendi en un instant de temps de l'emergència i com aquestes dos fonts de dades annexen al procés de simulació

Paraules clau - Incendis forestals; Aplicacions dirigides dinàmicament; Meteorologia; Models; Helicòpters; Simulacions

1 INTRODUCTION

Forest fires are a kind of natural hazard that affects countries of the Mediterranean area every year. To fight these disasters, a critical aspect is the response time of emergency systems and their ability to act in the most efficient way possible in order to avoid significant damages. That implies making key decisions as quickly as possible with only the support of existing information. The scientific community has expended great efforts in modeling wildfire behavior as accurately as possible to aid wildfire analysts during an ongoing hazard. Hover, these works have been focused on developing scientific simulation tools without being too much aware of the interdisciplinary challenge they were facing up. What is lacking in natural hazard prediction systems, like in the case of forest fire, is a system that integrates all existing data sources, fire spread simulators, extra models such as meteorological model, wind field model, vegetation model, among others, in a cyberinfrastructure that takes advantage of current high performance computing environments to provide accurate prediction result at real time.

When dealing with natural phenomena simulations, it is well known that input data accuracy becomes an important bottleneck. The input data required for any existing forest fire spread simulator consist of a set of GIS files (land use, fire perimeters from remotely sensed sources, meteorological data), which should be appropriately conflated. Two kind of files are used to describe this GIS data: Rater files and Vector files.

Rasters are a matrix of values representing a grid of the earth surface, each raster contains a single atribute of the grid and a stack of grid can be used to represend the diferent variables of the earth surface description. On the other hand, vector files are a queue of consecutive coordinates that represents a form. These forms are mainly three: points (one single coordinate), line (a sorted queue of consecutive coordinates) and polygon (a sorted queue of consecutive coordinates considering the area delimited by those points). In that example, the elevation files are descrived as a raster file of squared cells where each cell has an elevation value. The same example goes on metheorogical and wind data. Figure 1 shows both kind of files format.

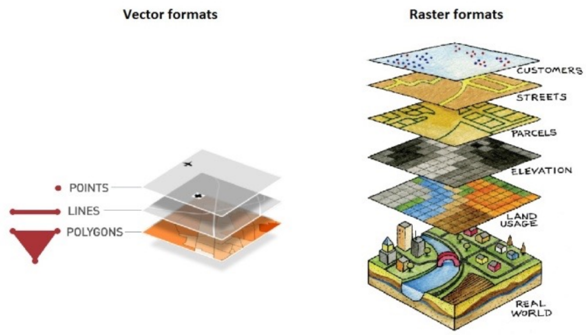

Fig1. GIS data format

The output delivered by a certain forest fire spread simulator consists of the fire position (perimeter) after a preset time interval. The high degree of uncertainty introduced in the process due to inexact input data results in a certain degree of error in the delivered predictions. However, any System that provides additional information about the near future behaviour of an ongoing forest fire is a very desired tool by the people in charge of taking forest fire mitigation decisions. This kind of Systems are called Decision Support Systems (DSS).

As it has been mentioned, one of the main problems related to the input data required to feet any forest fire prediction system, is the multiple input data formats that should be processed and adapted to be properly included into the system. In more detail, the general data required for wildland fire simulation are:

- Landscape map: It describes the land characteristics such as the elevation of a map position, the slope and aspect. The last two can be calculated from the first by a simple calucation of the neighbourhood cells. So, the relevant data in this case is the elevation map.
- Metheorological data: It describes the metheorological conditions such as the wind, temperature, humidity of the air conditions.
- Fuel map description: It describes the type of fuel in the fuel model combustion.
- Fuel map description: It describes the fuel characteristics of each type of combustion model and its initial conditions values to perform the combustion model.
- Simulation Settings: It describes the diferent parameters settings of the simulator such as the total time of the simulation, which is the initial

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date of the simulation, the resolution of the results, etc.

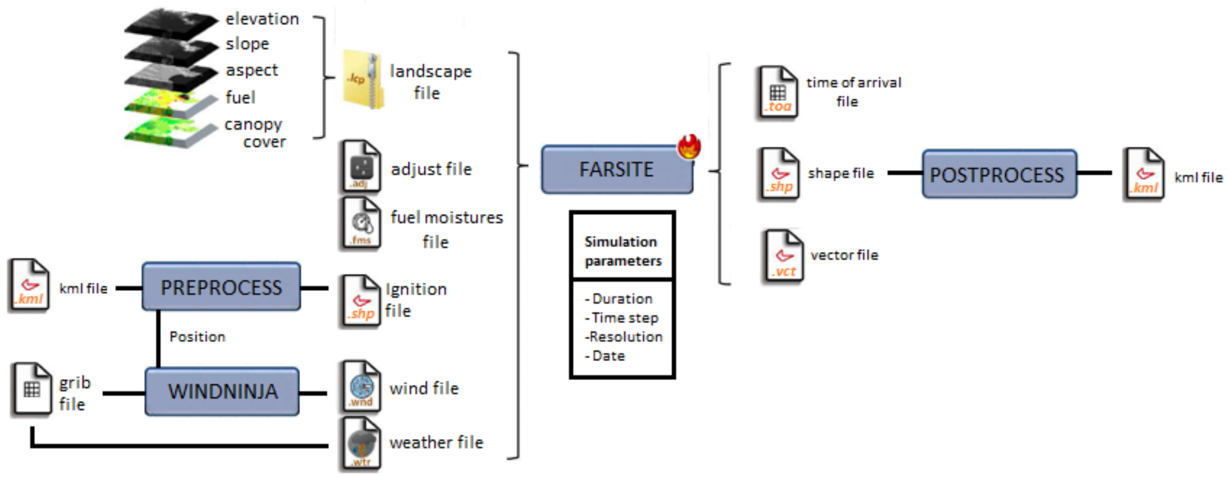


Fig2. System workflow

- Ignition point or initial fire perimeter: This data is a critical information. In order to be able to provide a forest fire spread prediction, it is necessary to know the initial fire position from where the forecast starts.

All this data is the basic input of the system. The core of the system is a wildfire spread simulator named FARSITE [2]. This simulator is widely used in the US by Federal and State land management agencies for predicting fire spread across the land-scape. It is based on the BEHAVE [3] a fire behaviour prediction system, wich itself is based on the Rothermel ‘s spread model [4]. It includes models for fuel moisture content [5], spotting fire [6], post-front fuel consumption [7], crown-fire initiation [8] and crown-fire spread [9]. Besides, there are a wide research works associated to this simulator [10,11,12,13], thefore, for this reasons FARSITE is one of best candidate to be used for the implementation developed in this work. The version that we use is a command-line version without user interface support, so it only contains the core model to predict the fire behaviour based on the input data and no direct output visualization is included. Any output provided by the simulator is delivered to files. This characterisctic allows to execute the system in any kind of computational environment in a background fashion.
One key issue when dealing with forest fire behavior forecast is the wind conditons. As it is well known, wind speed and wind direction are the most sensitive input parameters that are modify by the topography of the terrain. Therefore, it is mandatory to take care of this issue. For this reason, we have incorporated a wind field model in the system. The selected wind field is WindNinja [21]. WindNinja is not a weather forecast models, unlike common prognostic models, but is is a diagnostic model, that means, it computes the spatially varing wind field on the surface for one instant time but it is not able to forecat wind modifications among time. WindNinja requires as input parameters the elevation map of the underlying terrain, the meteorological wind speed and wind direction and the required output resolution. As output, WindNinja delivers wind speed and wind direction at each cell of the terrain at the specified resolution. Since WindNinja requires as intput the metereological wind speed and wind direction at a certain time, someway, we need to obtain the weather forecasted data to feet the system. In this case, the weather forecast information data is provided by the Servei Meteorologic de Catalunya (SMC).
So, finally, the main objective of this work consists of implementing an operational system to predict forest fire spread, which encompass all different data sources and formats in a compatible way to be able to run a forest fire spread simulation at real time. The workflow required by this system is shown in the figure 2.

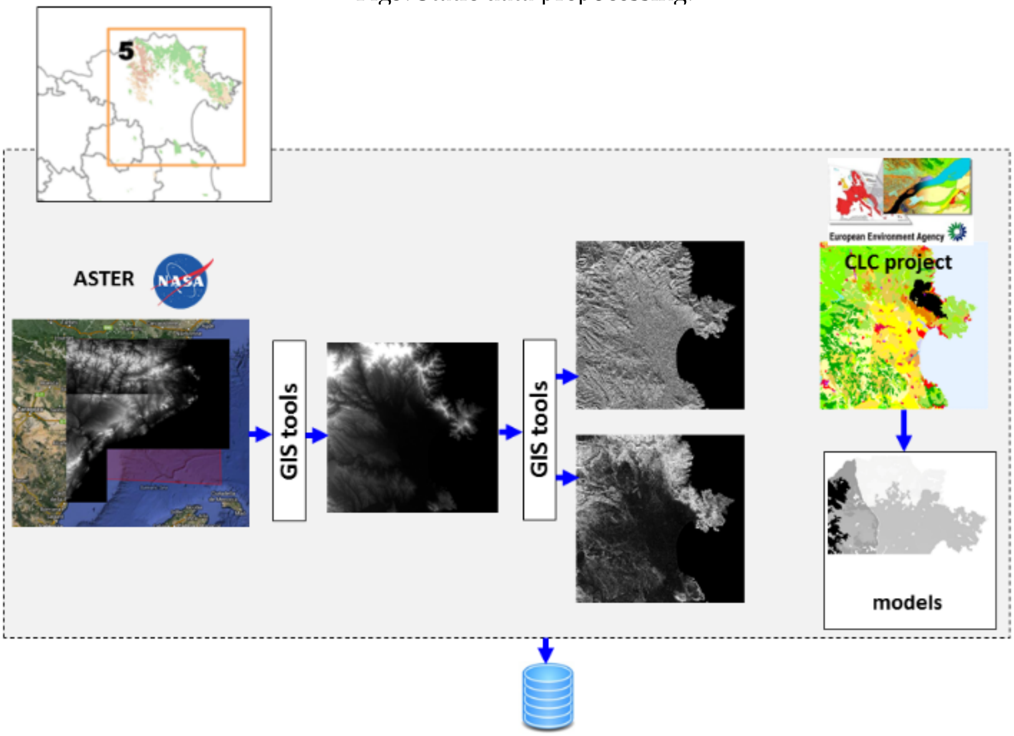
Subsequently, in the objective section, a more detail description about how all the required dats is gathered and processed to deliver a forest fire forecast at real time is included.

2 Objectives

In this section, the data sources and how they are preprocessed to properly feet the system are described. Furthermore, the how the simulation output is executed on a cloud platform and how the output is postprocessed is also included.

Depending on the dynamism of data changes during the simulation interval time, the input data can be grouped into tow blocks: static data and dynamic data. The first group includes the information that does not change during the ongoing process such as: elevation surface map and fue distribution map. This data can be stored in an

Fig3. Static data prepocessing.



offline moment to adapt their format and have them ready to be coupled to the simulator interface format and then gathered along all the simulations. The second group are: ignition position (initial fire perimeter) and weather forecast data. Both of them are impossible to know in a previous stage and have to be proccessed at simulation time. Because of that a preprocess module has been implemented to accomplish format requirements.

The current version of the system have the following data sources:

2.1 Static data sources

Topographic Information:

The three input layers required to properly describe the forest's topographic area where the _re occurs, are the so called elevation, aspect and slope maps. The elevation map or DEM (Digital Elevation Map) is a simple, regularly spaced grid of elevation points, which provides a discretization of a continuous surface, taking into account measures in certain points of the terrain. The maximum resolution of the imaging resources define how many measures we can achieve in a certain area. Slope and aspect can be calculated using the elevation, and applying certain equations. In DEM files based on regular square cells, slope and aspect of every cell is determined by the altitude of some specific neighbors, depending on the chosen method. These parameters determine the roughness of the terrain and have a direct influence on fire spreading.

- Vegetation map:

The vegetation map, also known as fuel map, shows the vegetation diversity of the area. Each vegetation or fuel type has its own parameters such as moisture content, ammability, fuelbed load and density, heat content, etc. These kinds of maps consider a limited group of standard fuels that represent the great diversity of possible fuels and parameters. In fire spread prediction, each of the standard fuels present on a map has a list of parameters about the content moisture of such fuel. Fuel moistures are those parameters that de_ne the content of water of live and dead fuel. The concept of live fuel is related to the live vegetation of the area (trees, bushes, grass, etc.). Dead fuel is the vegetation that remains lying in the 4 litter of the forest oor. These moistures have a direct impact in the fire spread rate.

There is another kind of map, concerning the vegetation called canopy cover map. This map shows the percentage of tree crowns present on each terrain division. This information will affect the fire typology, since it does not spread in the same way a surface fire than a crown fire.

The process of gathering the above mentioned static data is depicted in figure 3. As it can be seen, the DEM is obtained from the ASTER instrument aboard the NASA' satellite and the desired window is clipped. Any time needed to process this information could be done duing the no fire season , in order to have it ready during the forest fire season.

2.2 Dynamic data sources

- Ignition map:

Ignition files are generated in collaboration with the Helipistes SL company. This enterpimse has a fleet of helicòpters and are in charge of carrying the comander of the firefighter during and ongoing hazard. The way of obtaining the fire perimeter consists of tracking the GPS position of the helicopter over the perimeter of wildland fire in a certain moment of time. The file contains an *id* (identification) to identify the trace figure and a time register of the moment when it was made. The format is stored in a specialized version of XML which is KML, a google standard for Google maps to draw figures. The preprocess module extracts the line of the perimeter and generates a shapefile with the specific georeferenced transformation for Catalonia region. Since the original georeferencing is WGS 84, the system requires a transformation to the regional georeferencing EPSG: 3042. This change adapts the representation of the points coordinates to a better representation over a 2D model.

Furthermore, the centroid of the figure is extracted and a window for the simulation is generated. Taking this centroid, a square of 30km of side. This windows parameters are used to cut the all the maps in chunks for several reasons. The main reaon is that with this process the memory requirements keeps low while all simulations are generated. Furthermore, with this method, boundary conditions of maps are eliminated while the windows can fit in the stored maps. Once the simulation has finished the output file is postprocessed in the same way that the ignition perimeter but in the opposite way. As a result, the output shape file that contains the perimeter positions behaviour along the simulation is converted back to the kml format.

- Weather forecast

The weather forecast is generated for the regional meteorological service of Catalonia (www.Meteo.cat). A research agreement has been done with the diferents members of the project to get the predictions for the system. While the fuel and elevation map domain is Europe, the domain of the weather data is, right now, only for the Catalonia region but, it can be computed for any part of the planet if required. The raster file is in a grib format, which contains a stack of diferent meteorolgical conditions but the ore relevant are: the humidity, temperature, wind speed at 300m high over surface and the cloud cover. The weather conditions are extracted to generate the weather file, and the wind speed of the centroid of the fire is obtained too.

Once the axis of wind speed is extracted and the cloud cover too, the data is introduced to the Windninja wind field simulator, as a result a wind grid file is generated ready to use by the FARSITE Simulator.

2.3 Simulation/Prediction process

Right now, we know the preprocessing requirments of the basic data need by the operational prediction system, so, we can explain in more detail how the simulation/prediction is performed.
A strong requirement in this system is the Real Time Response. Any forecast system to be useful should deliver the prediction under strict real time constraints in order to be useful. Furthermore, the computational environment where the system is allocated should be up 24 hours a day during the forest fire season. For that reason, different execution platforms where analyzed to determine which one has a minimum Quality of Service. The platform selected to maintain the system was a virtual machine in a clud environment (such as Amazon). In particular, a running server has been allocated in the cloud what simplifies and speeds up the development of the system because it was not necessary for the company to buy any extra hardware platform.
The server has been configurated to be feet with the preprocessed information gathered from the different above mentioned sources. The most problematic part is the one associated to the dynamic input data (fire perimeter and weather forecast). In the first case, the helicopter tracking flight system is aboard the helicopter and is started by a specialized operator. This system requires a good connectivity to the cloud service, in order to send the perimeter without any loose of information due to sudden connexions intermitences. For that reaon a connexion control protocol has been developed.
On the other hand, the weather forecast data is another information that cannot be processed in an off-line way but should be properly evaluated every day. Consequently, twice a day, we download from the SMC the grib file with the weather forecast information from the whole Calatunya region at a resolution of 3km and information related to weather variables at a time interval of 1 hour.

2.3 Forest Fire Simulation

Once all required data processing has been done, it remains to execute a forest fire simulation to provide the fire behavior forecast. This step consists of receiving all data and execute FARSITE with the simulation horizon requirements properly set up. The fire evolution is delivered using isochrones with the desired time step. These outputs are in shape file format that should properly transformed to kml format and send it back to the movile device aboard the helicopter for visualization pruposes. In particular, the static and dynamic data must be properly fitted to FARSITE to outcome with a well georeferenced output propagation fire perimeter. FARSITE is a simulation engine, which consist of a spatially explicit wildfire growth model that requires spatial information regarding topography, fuels, initial fire and weather parameters, which are organize as follows:

– (.LCP) file, which consists of an encapsulated landscape file that includes the elevation, the slope, the aspect, the fuel model and the percentage of canopy cover for every cell of the terrain.

– (.WTR) file, which includes weather data consisting of the maximum and minimum temperature and humidity per day.

– (.WND) file, which includes the wind information. More precisely, this file contains as many lines as wind samples captured or predicted. Every line must indicate the hour and the wind components. If working with wind fields, the files associated must be attached.

– (.ADJ) file, which keeps an adjustment value for each vegetation type. This value is a factor that modifies the rate of spread of the corresponding vegetation type. This factor allows the user to fit the standard vegetation types to the specific vegetation of the fire.

– (.FMS) file, which includes an initial fuel moisture factor for each vegetation type. These factors regulate the moistures values of each vegetation.

From all these input files, the one directly related to the Topographic Area is the landscape (.LCP) file. Therefore, when using the FARSITE simulator, one has to generate one landscape file for window delimited by the topographic area where the fire is taking place.

2.3 Decision Support System workflow

As we have mentioned, the main objective of this project has been to deploy a real time forest fire prediction system that could be used in a test mode during the summer of 2016. This kind of frameworks provides information to the firefighter to help them in taking critical decision during a fatal event. In this sense, the work developed in this work is part of a Decision Support System (DSS), which main purpose is to aid the people in charge of taking decision but, this kind of systems will never replace the final human decisions. The workflow of this DSS can be sumerised in the following steps:

Step 1: Get data from the real fire perimeter to generate the simulation ignition file. The information is gathered from a movile device aboard the helicopter.

Step 2: Sent the perimeter (kml format) to the cloud server.

Step 3: Evaluate the fire centroide based on the obtained fire perimeter.

Step 4: Get meteorologic and surface data from the fores fire environment to feed the simulator.

Step 5: Select a simulation domain window based on the centroid of the forest fire.

Step 6: Transform gathered data to the simulator interface format.

Step 7: Perform simulation based on the input data and the configuration parameters.

Step 8: Post process output simulator data to data server format interface.

Step 9: Sent the predicted perimeters (kml format) back to the device aboard the helicopter.

The system should be up during the fire risk season in order to start working at any time when required. Currently, the system is working as a testing prototype.

3 State of art

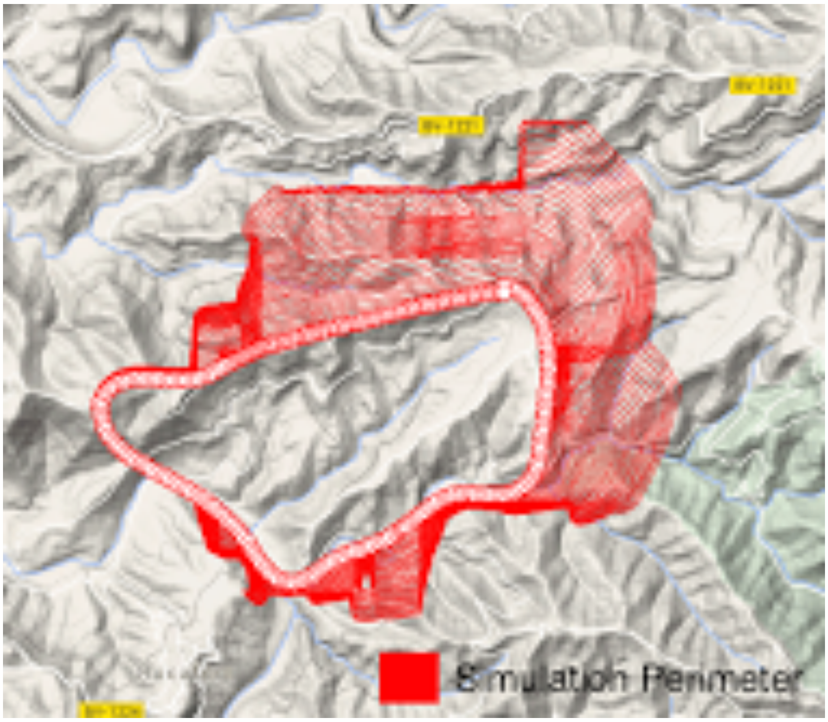
The main difficulty in this project is lack of any kind of system that performs this scheme around the world. Similar implementations has been done in Europe but using different resolutions and data sources. The system wants to be part of the European Forest Fire Information System (EFFIS). EFFIS was established by the Joint Research CEnter (JRC) and the Directorate General for Environment of the European Commission, in close collaboration with the Member States and neighbour countries, to provide harmonised information required for international collaboration on forest fire prevention and fighting, specially in cases of trans-boundary fire events. The EFFIS system supports the services in charge of the protection of forest against fires in the EU countries and provides the European Commission services and the European Parliament with updated and reliable information on wild land fires in Europe. EFFIS system has evolved until now a fire monitoring system that comprises all the phases of forest fires, from the pre-fire assessments to the post-fire estimations of damages and the analysis of vegetation recovery [14]. These modules are feed with data providing from EU Fire Databases and satellite images (MODIS images). The Fire Detection geoparses the fire news with the MODIS hot spots, in order to identify fire burn areas perimeters. Those perimeters are available at EFFIS from the Burnt Area Map module. On the contrary, our system obtain its ingition data files as a result of the position of an helicopter arround the perimeter of the wildland fire in a certain moment. So, the system developed in this work could work in regional areas with a more precise resolutions and time steps.

3 Methodology

The selected methodology to develop the system was

SCRUM. An iterative and incremental agile development framework for managing product development. SCRUM key principle is its recognition that during production process, the client can change the requisites about what they want and need [15]. That unpredicted challenges cannot be easily addressed in a traditional predictive or planned manner. As such, scrum adopts an empirical approach-accepting that the problem cannot be fully understood or defined, focusing instead on maximizing the team's ability to deliver quickly, to respond to emerging requirements and to adapt to evolving technologies and changes in market conditions. For that reasons and, based on our project characteristics, that do not have a precedence to contrast the results, we hae decided to use SCRUM. The main basis of this selection is that, initially, the project forces to define the requirements on what has to do but not on how has to perform it. Furthermore, the fire department requires a previous prototype to ensure the demo in order to couple it in their protocols. Another point is that the system can easily to be splitted in modules with a certain simple interface, so each SCRUM loop can choose a different chunk of work according to prototype deliver requirements.

Along the development proceess, each week a meeting was made with the CTE of Helipistes in order to track the



progression. On the other hand, those meetings were used to list the client requirements and to discuss what work sections were more important because we had 3 demo testing with the fire department. The importance of delivers were high enough, so each one in the SCRUM loop we had time to share a moment of how we could face the problems that had been blocking the development process.

4 RESULTS

After all tests that has been done to ensure the consistency of the process, an iterative simulation workflow is made. An online method with web interface and iOS application clients has been coupled to interact with this system and as a result of this work you can see how an initial perimter done by an helicopter as is shown in the figure 4, can be finally processed and generate and outpu corresponding to the forest fire behavior forecast (see figure 5). In this particular example, the simulation settings has been stablished to be a total horizon time simulation of 6 hours with a time step of 10 minutes. Each 20 minutes a perimeter was printed out in the device abord the helicopter. The whole process has been done in 36 seconds.

5 CONCLUSIONS

The current project stands for an on-line operational simulation system, putting the main effors not for the kind of simulator used and the precision of its results but as an integrated scheme coupled with the operational forest firefighter members. Apart from the quality of the results, the goal is to open a door where to fit this technology and to consolidate protocols by using this application, and then, other techniques can improve the results on time [16,17] by using some algorithm of calibration of the input simulation parameters [18,19,20]. Based on the tests already done and the results of the test that will be done in the current summer campaign, we will see the effectiveness of the system. By the moment, the system is in testing development process and the test already done shows the effectiveness of the system not for the quality but for the operationally, so, because of this the system has accomplished the objectives.

ACKNOWLEDGEMENTS

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