ArcFIRE™/ArcFUEL™: Forest Fire Management Geoplatform and fuel maps

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Abstract

ArcFIRE™ is a state-of-the-technology Integrated Wildland and Forest Fire Management Geoplatform under constant technology evolution since 1990, progressed at high-tech institutions of international competence, but also withdrawing on US Forest Service modelling technologies. The Geoplatform captures the vital dynamics demanded by Planers and Decision Makers engaged in the Forest Fire Life Cycle. ArcFIRE™ has been used in numerous operational tactics in France, Greece, Italy, Spain, Portugal and other countries. It is worth noting that practically all forest fire management activities require a good assessment of vegetation cover in the management area in the form of a fuel map. It is widely recognized that the availability of updated and accurate fuel cover maps is one of the limitations for fire prevention plans, fire spread simulation and for recovery plans. ArcFUEL™ is a LIFE+ Project that involves six European Partners with the objective of producing updated fuel maps to be used in forest fire management operations and geoplatforms as ArcFIRE™. This paper outlines the: (i) usage of ArcFIRE™ as an Integrated Wildland and Forest Fire Management Geoplatform for the four phases of the Forest Fire Management Cycle: Awareness (Preparedness/Prevention), Emergency, Impacts and Dissemination, (ii) technology used for its development, (iii) architecture implemented, (iv) methodology of production fuel cover maps based on satellite data and field validation to fulfil the needs of local, regional or national users.

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(v) case study of the suburban forest SeihSou, Thessaloniki, Greece where ArcFIRE™ is successfully installed.

Keywords: wildland, forest fire management, geoplatform, fuel maps, fuel types, LIFE, ArcFIRE, ArcFUEL, ESRI ArcGIS.

1 Introduction

Statistics show Forest Fire (FF) hazard is continuously increasing in the Mediterranean and in Greece in particular. Up to 1975, the average annual burnt area at National Level was approximately 127.000 acres/year for an average frequency of 650 fire events. Thereafter and up to 1998, the average burnt area reached 487.000 acres/year for an average frequency of 1.713 fire events, namely a 250% increase. Main Driving Factors are: (a) lacking of forest management practices (e.g. biomass accumulation), (b) mismanaged spatial planning and inappropriate land use practices and patterns such as extensive transition zones between urban and rural zones (WUI, wildland urban interface), (c) socio-demographic factors such as population distribution, unemployment, (d) climate change and extreme weather conditions (draught, heat), (e) economic factors such as livestock and agrarian production, and (f) low resources availability to monitoring mitigation.

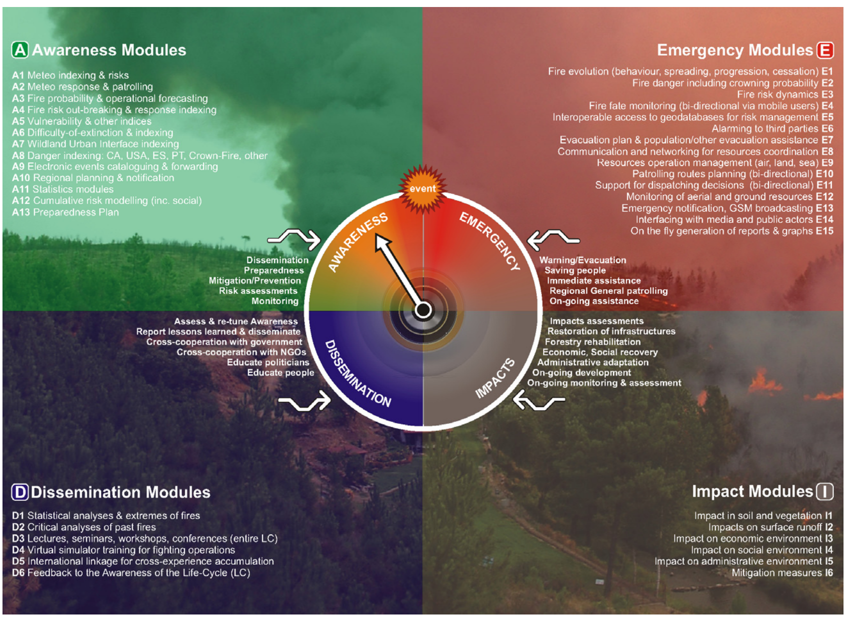

Figure 1: Life Cycle (LC) stages in Forest Fire (FF) management.

ArcFIRE™ and ArcFUEL™ are products supported by various operational modules. ArcFIRE™ is a scalable, modular and customizable technology geo-platform that provides management solutions for the "entire spectrum" of the FF

Life-Cycle as demanded Civil Protection Authorities (National, Regional, State, Local) and government and private operations. It captures four stages of the FF Life Cycle via four Modules {A}-{D} (Figure 1). ArcFUEL™ is a fuel mapping service that its goal is to produce fuel classification maps from readily available data: EOI and Ancillary data (GIS, ground truth).

1. Awareness Module {A}: Delivery of significant statistics, means and tools, models and decision rules, to analyzing national, regional and local situations, and to forecast short-term and long term circumstances and risks "prior to a fire". To this end it provides: (i) Preemptive Methods and Tools to assessing and reducing risks based on maps, meteorological data, statistics and regional practices, (ii) Early Warning Tools linked to sensors, cameras and spatial technologies to ensure preparedness and prevention, (iii) Key indices and maps on meteo risks, FF risk out-breaking, danger indexing (e.g., CA, US, ES, PT, crown-fire), preparedness and prevention indexing, and (iv) an integrated mapping system as visual guidance for "a day's" conditions.
2. Emergency Module {E}: Dynamic integrated commutation, surveillance, modelling and information tools assisting planners-, decision makers- and fire fighters- in missions "during the fire". To this end it provides synthesis of dynamic information and decision support services as: (i) Fire evolution and behavior dynamics, (ii) Dynamic Fleet Tracking and Fleet Rooting linked to actual and forecasted fire-front evolution, (iii) Evacuation assistance, (iv) Ground-Air Resources Management in terms of capacity-, resources fatigue- and availability, and (vi) Dynamic Emergency monitoring and re-streamlining processes
3. Impacts Module {I}: Delivery of statistics, techniques, procedures and means to assessing and quantifying environmental, economic and social impacts "after the fire" as: (i) Post-fire flood and Erosion Risk based on terrain characteristics, burnt area and fire severity, rain and annual regional statistics, (ii) Post-fire socio economic damage in respect to burnt area, timber and agrarian loss, recreational value, (iii) Post-fire administrative and fire fighting performance, and mitigation measures and other.
4. Dissemination Module {D}: It provides statistics, information on world best practices and on "lessons learned" from past fires, and as such it provides feed-back to previous modules. As such it offers: (i) Spatial-temporal information on "FF history" and spatial analysis tools to extracting "FF patterns" linked to landuse, fuel maps, meteo-conditions, and other, (ii) White papers, manuals, lectures, workshops and conference material, and (iii) References on a cumulative knowledge of European and international experience, state-of-technology webGIS training, virtual simulators for fire fighting operations, and other.

2 ArcFIRE™ and ArcFUEL™ technologies

ArcFIRE™ and ArcFUEL™ deliver multiple technology advancements, as:

- S/w Architecture: ArcFIRE™ is built on ArcGIS ESRI™ s/w Technology. It is operated as a Desktop GIS application (local), or as a Web Application providing WebMap Services (WMS) to the end-user (fixed or mobile). It cooperates with Google Earth/Maps™, Virtual Earth™ and ArcGlobe/ESRI to make the ArcFIRE™ layout familiar to a wide non-expert audience.
- Interoperability: ArcFIRE™ follows an open modular Architecture to constantly incorporating new emerging Modules for FF management. To this end, it adopts Global Technology standards at all operational Layers: Geo-information Layer, Application Layer, and Service Layer. Most common standards are INSPIRE, OGC, XML/GML, TCP/IP, web services (SOA) and HTTP.
- Info and meteo: ArcFIRE™ relies on meteorological forecasts of high accuracy and spatial resolution to make reliable simulations of the fire front evolution. To this end it interconnects with established Weather Forecasting authorities and university teams (e.g., MeteoGrid SA, Epsilon-Group, NTUA) and utilizes a standardized protocol developed for explicit forecast data-transfer upon-demand via standard data-formats (e.g., ESRI, ASCII, GRIB).
- Geo-information: ArcFIRE™ operates on top of custom Spatial Data Infrastructures (SDI) that meet platform's requirements. The SDI distinguishes "Static Data" that bare some or no changes in the long-term (e.g. fuel map, terrain) and "Dynamic Data" that bare significant changes in the short-term (meteorological maps). SDI incorporates a metadata Architecture that adheres to the spatial-dynamic nature of ArcFIPE™ Data and meets OGC and INSPIRE standards.
- Land/Soil/Forestry: ArcFIRE™ emphasizes on Fuel Model Maps. The Fuel Model Structure applied is in an open XML catalogue legible by the non-experts and fully scalable to include future extensions for both Surface and Crown Fuel Models. Standard Catalogues included those of Anderson (1982), Prometheus (1999) and Scott and Burgan (2005). Custom catalogues included adhere to several case studies in the Mediterranean (e.g., SeihSou, Cordoba). A catalogue is being developed under EC/Life+ funding, the ArcFUEL™, to be available in early 2013.
- Sensors and cameras: ArcFIRE™ interfaces to Sensing Systems to achieve early detection of the FF event. For small areas of high risk, wireless sensor networks and Meteo Stations are used. The WSN is energy efficient, self organizing structures of sensors that transfer raw-measurements over standard wireless protocols (IEEE 802.15.4 standard Zigbee) usually at 868 MHz. Measurements are delivered to ArcFIRE™ at an XML format. Meteo Stations communicate over GPRS/3G or Wireless Access Networks where available. Measurements are managed over standard data-logger protocols (CR800). For larger areas, a structure of IP PTZ to monitoring cameras are used (G4S, ©Bosch) with: day/night operations, wide dynamic range, IP (MPEG-4) connectivity, advanced alarm control, UTP transmission standard, and other technologies.

- Communications: ArcFIRE™ can use multiple communication systems as GSM/3G Networks to interact with mobile units: get information on the status of operation (position, availability etc) and offer WMS with real time information. ArcFIRE™ can employ hybrid satellite (GlobalStar/Iridium) next to the ground communications (GSM, 3G) to achieving 100% coverage for the Area of operation even under extreme conditions.
- Fire dynamics: ArcFIRE™ pushes the state-of-the-Art on FF Propagation Modelling including Wind Field modelling (New ATMOS, UoA/2010), Surface Fire Propagation (Rothermell Model), Crown Fire Propagation, Stochastic Propagation including wind perturbation, and other features.
- Control Command Centre (CCC): The ArcFIRE™ Communications Control Command Centre coordinates all Modules and establishes high availability communication pipelines. It is equipped with a dual server, clients, TV monitoring stations, and other facilities.
- Fuel Classification Mapping: ArcFUEL™ uses remote sensing, along with vector GIS and ground truth data which are important components of fuel models mapping efforts and fire hazard mitigation. Especially satellite remote sensing data is a sound alternative to map fuel types at different spatial scales, since it provides a spatial view of vegetation characteristics.

3 ArcFIRE™ architecture

ArcFIRE™ is based on a three Layer Architecture and implements a Client-Server schema of operations (Figure 2).

1. Application Layer: Clients in the Application Layer operate a Desktop tool which hosts all ArcFIRE™ modules. The Desktop tool can be ESRI/ArcMap™ and Extensions ("heavy" client) or ESRI/ArcGIS™ Explorer ("thin" client- to be implemented soon). The Desktop Tool consumes services published by the Server Layer in order to handle input/output for all ArcFIRE™ Modules. Mobile Clients are offered only E1 "Fire Simulation" out of all ArcFIRE™ modules. They use a mobile device carrying ESRI/ArcPAD™ and consume one Service from the Server Layer (Simulation Mobile) to load on the PDA a recent Simulation Map.
2. Server Layer: The Server Layer is an Interface between the Desktop Clients and the Data Layer. It operates a list of Services that handle the Data-flow from the Data-Layer to the Application Layer and backwards. The Services apply only for the Data under the Folder Structure and not for the Data already managed by the SDE or the RDBMS. Data-flows are triggered under client requests when he/ she attempt to run an ArcFIRE™ module. To this end, the Server Layer:
   - Adheres to requests for input data coming from a Client and checks in the Data Layer for availability. If data are available then returns the data to the Client (Application Layer) otherwise informs the client that data requested is not available

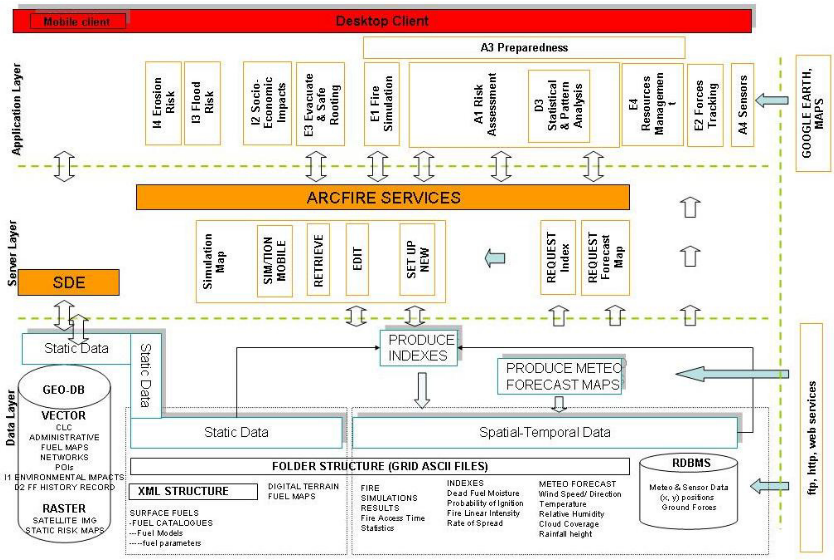

Figure 2: ArcFIRE™ architecture.

- Makes sure that output from ArcFIRE™ modules is properly stored in the Data Layer so that is accessible from all Clients

depicts the Services implemented at the Service Layer:

- "Request for a Forecast Map": the Client-Desktop asks for a particular meteo-Forecast Map in regards of content (e.g. Temperature) and Date/ hour of issue (e.g. 2010/07/21 15 00). The service finds and returns the Map from the Data Layer. The Map either appears on screen or it is used as input for the ArcFIRE™ modules A1, E1, I3.
- "Request for an Index": the Client-Desktop asks for a particular INDEX in regards of content (e.g. Meteo Probability of Ignition, Dead Fuel Moisture etc) and Date/ hour of issue (e.g. 2010/07/21 15 00). The service finds and returns the Map from the Data Layer. The Map either appears on screen or it is used as input for the modules A1, E1, I3.
- "Set-up a new Simulation": the Client- Desktop is about to set-up a new simulation at a particular Fire Ignition Time Stamp (Date and time the Fire is supposed to start). The Service checks the Data-Layer for availability in Wind Speed, Wind Direction, Relative Humidity (Forecast Maps) and Dead/ Fuel Moisture (Indexes) to be used as input for the simulation. Available Maps and Indexes close enough to the Fire Ignition Time Stamp are returned. After the simulation runs, results are stored in the Data- Layer to be accessible by all Clients. Results are uniquely identified per simulation with a complex meta-data architecture not be described here in detail. In general, the meta-data parameters are the Fire Ignition Time Stamp, the Time Stamp of Forecasts, the user id etc.

- "Edit a Simulation": the Client- Desktop searches and retrieves a past simulation result for editing. Search is based on the abovementioned complex meta-data architecture. Editing means to change: Fire Ignition points or Simulation Time (duration) but keep constant both the Fire Ignition Time Stamp and the Input Forecast Maps and Indexes. The outcome (edited simulation) is correlated with the original simulation and this reflected in the complex meta-data architecture.
- "Retrieve a Simulation": the Client- Desktop searches and retrieves a past simulation result for visualization. Search is based on the abovementioned complex meta-data architecture
- "Simulation Mobile": the Client-Mobile retrieves the most recent simulation result for visualization on the screen

3. Data Layer: The Data Layer contains all GI Data related to ArcFIRE™ Modules and Operations (input or output). Data are either Static or Spatio-Temporal (Dynamic).
   - Static Data bare some or no changes in the long-term; e.g. the Fuel Model Map that is altered occasionally after a Forest Fire or refined after a Site Survey Campaign. Static are also Terrain Maps such as the Digital Elevation Model.
   - Spatio-Temporal (Dynamic) Data bare significant changes in the short-term. Dynamic Data are further divided into several sub-Classes: (i) Fire Simulation maps (ii) Indexes related to Forest Fires (iii) Meteo Forecast maps (iv) raw sensor data (v) telemetry data x, y positions

The Data Layer is structured in separate modules:

- Geodata Base (GEO-DB). The GEO-DB contains Static Data only in Raster and Vector format. Most important Data are Digital Terrain, Fuel Maps, CLC, Networks (road, power), and Static Risk Maps, Satellite Images, I1 Environmental Impacts Layers (Burn Severity, Curve Number etc) and D2 FF History Records. Data in GEO-DB are not used by ArcFIRE™ modules apart from the SFR which is used for "A1 Risk Assessment". Access in the GEO-DB is managed via the ESRI™ SDE.
- Folder Structure: Contains both Static and Dynamic Data mostly in GRID-ASCII format. Most Important Static-Data are the Digital Terrain and the Fuel Map. The Fuel Map is accompanied by a scalable XML structure that assigns flammability parameters to each Fuel Model recorded on the Map. Most Important Dynamic-Data are Fire Simulation, Indexes and Meteo-Forecast Maps. The Folder Structure consists of a levelled schema presented next.

- SSS: scene identifier e.g. 001. All files (static and dynamic) that are under the same scene have the same geographical extent, resolution and projection system.
- YYYY: Time Stamp the Forecasts and INDEXES are issued (year)
- MM: Time Stamp of Forecasts and INDEXES are issued (month)

- DD: Time Stamp of Forecasts and INDEXES are issued(day)
- yyyy: Fire Ignition Time Stamp (actual year)
- mm: Fire Ignition Time Stamp (actual month)
- dd: Fire Ignition Time Stamp (actual day)
- sss: simulation session. Each day yyyymmdd might have up to 999 simulation sessions. Each session identifies a simulation for a particular hour and minute of the day yyyymmdd.
- The RDBMS contains only Dynamic Tabular Data. Most important data are raw sensor - data and telemetry data - (x, y) positions of ground/ aerial forces.

ArcFIRE™ allows the user to de–centralize some piece of the Data and transfer it from the Data Layer to the Desktop-Client (Application Layer). Such Data could be (i) the Fuel Maps (both the Vector and the GRID ASCII version) (ii) the XML structure of the Fuel Maps (iii) The Static Risk Map (SFR). The expert-user can treat these data as local with "full rights" than as global with "read-only" rights. The benefit for the user is that he/she can edit the Fuel Maps and their XML structure in order to incorporate custom Fuel Models within the ArcFIRE™ simulations or risk assessment.

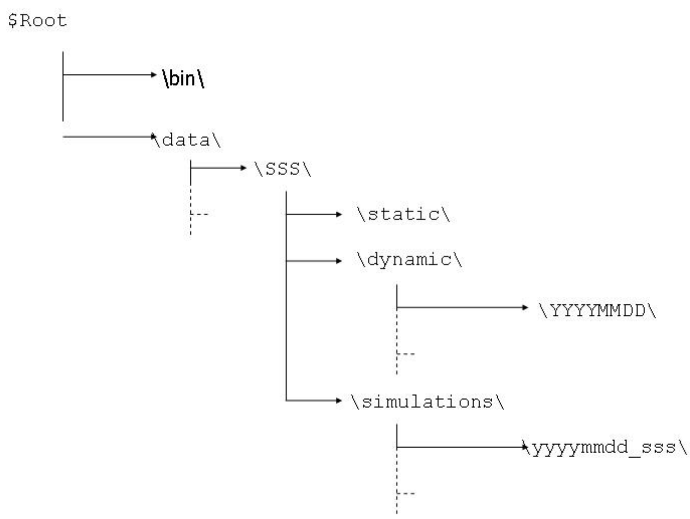

Figure 3: Folder structure schema.

The Data Layer carries also some Preliminary Processing that produce the following 2nd order Dynamic Data: (i) Meteo-Forecast Maps, (ii) Indexes.
The "Meteo-Forecast Map" process receives raw-Data in ASCII or GRIB format from the Meteo-Forecast System via ftp services. Then, applies a complex workflow based on GIS functionalities to georeference the measurements and create an ESRI-GRID Forecast maps at the appropriate extent, resolution and projection system.

The "Indexes" process receives as input the ESRI-GRID "Forecast maps" and the Digital Terrain Data plus the Fuel Model to produce INDEXES related to Forest Fires such as Dead/ Live fuel Moisture, Meteo-Probability of Ignition, Fire .Linear Intensity, Rate of Spread.

4 ArcFUEL™ methodology

Effective Forest Fire (FF) Management requires knowledge of Fuel Classification Maps (FCMs) that are poorly available in Mediterranean countries since: (a) they are produced only at local or regional scale, without any regular updates and no standardized methodology, (b) they are not produced via a standard structure or harmonized according to INSPIRE, (c) they are heterogeneous as produced via different methods at different dates.

Therefore available FCMs cannot support the systematic use of FF modelling at operational levels (prevention, suppression planning) of FF management. ArcFUEL™ aims to cover this gap, and (a) Standardizes a production flow producing FCMs (b) Develops an INSPIRE procedure for FCMs production. (c) Produces pilot FCMs for Greece and Portugal (full countries), Italy and Spain (pilot regions). The methodology and the FCM Web-Geodatabase significantly contribute to all four phases of any Forest Fire (FF) Management and Life Cycle (Figure 1) (i) Awareness (ii) Emergency (iii) Impacts (iv) Dissemination; and especially to the first two stages of the FF/LC: Awareness and Emergency during a FF.

Figure 4 depicts the whole ArcFUEL™ workflow divided into following steps:

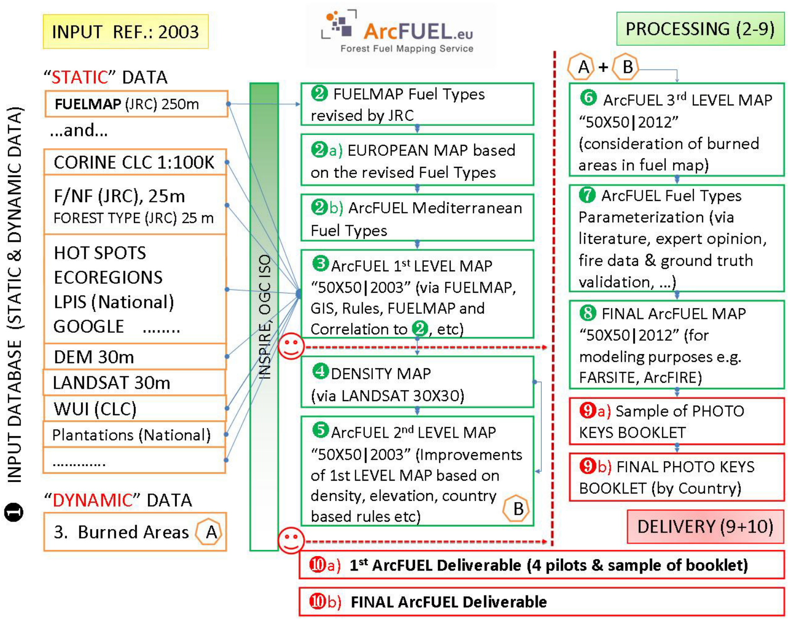

Figure 4: ArcFUEL™ overall workflow.

5 ArcFIRE™ installation in SeihSou

The SeihSou Forest, Thessaloniki, Greece, covers an area of 27 km^2. It is a clear 20 km^2 long Wildland Urban Interface (WUI) exposed to dense human activity. The Forest environmental and socio-economical value is high. As such, the Forest has experienced severe fire disasters in 1994 and 1997, and has been re-forested several times since then. ArcFIRE™ recently installed, would have been extremely useful in 1997: the Wind Direction changed abruptly only 2 hours after the Fire burst and this changed the Fire–Front Evolution in a way that disorganised the Civil Protection Authorities plans. Tests made with ArcFIRE™ under conditions similar to those in the 1997 event, show that ArcFIRE™ would have helped authorities to manage Fire suppression in an effective way.

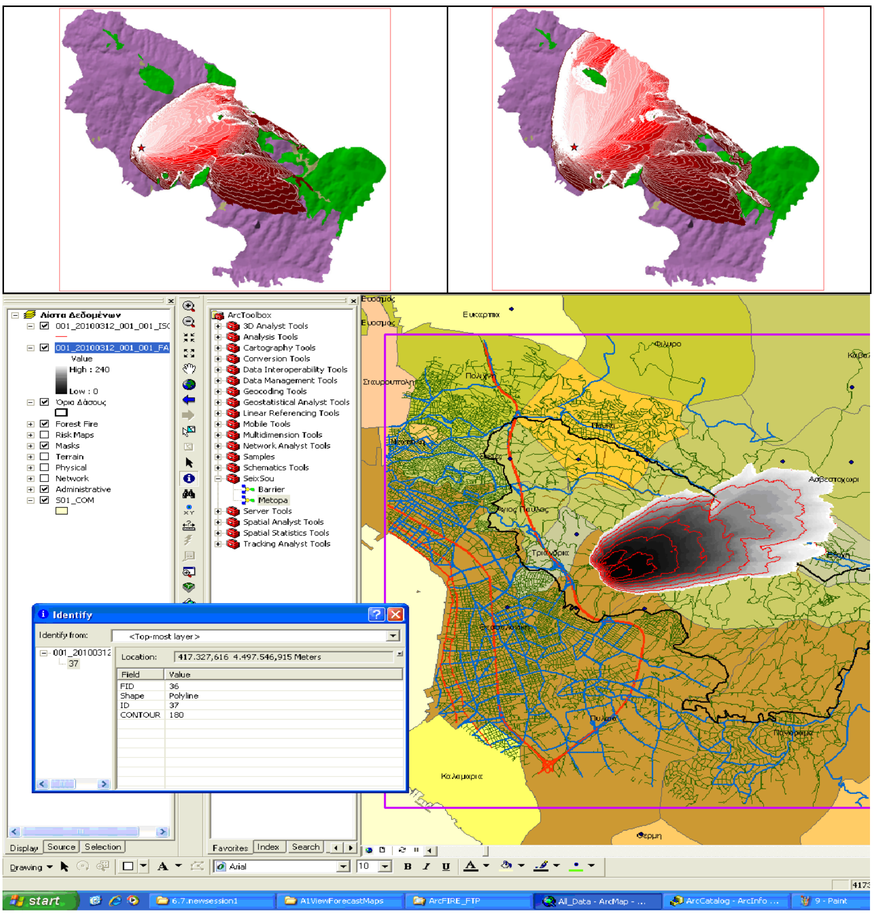

Figure 5: Tests in the SeihSou are for the 1997 hazard.

SeihSou in statistics:

- Installed on the 15th March of 2011 and was fully operational for the Fire-Season in 2011
- Offers a dense network of 16 IP PTZ dome cameras (Bosch), and 3 meteo-stations. Video Recording for 15 days. Unlimited records for meteo-measurements
- Provides High Spatio-Temporal Resolution of Forecast Maps: Grid 1km, 1 Forecast per hour, 8 Forecast horizon 120 hours
- Available are 15 certified custom fuels models
- Feasible are 999 simulation sessions per day/ per users. 999 edits per simulation session
- Active Clients are 3 Desktop and 6 Mobile Clients. Number of potential clients practically can go up to 50.

6 Conclusions

The ArcFIRE™/ ArcFUEL™ Team can transfer technology and can assume co-ordination of various types of actors as administrations and civil protection bodies or fire fighting and civil protection resources utilizing the ArcFIRE™ platform and ArcFUEL™ services.

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