A GIS -BASED FOREST FIRE MANAGEMENT INFORMATION SYSTEM

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1. INTRODUCTION

Forest fires that occur in the arid and semi-arid regions of the world have disastrous social, ecological and economic impacts, causing loss of life and property, loss of vegetation, of oil and water resources. Computers and electronic devices are increasingly being employed in spotting, monitoring and combating forest fires, providing assistance to the tools traditionally used in fire management.

Land based, airborne or satellite based sensors are thus used for forest fire detection, mapping and combating, making use of infrared thermography, laser technology, video, aerial photographs and Global Positioning System technology (Ciesla, 1993). Appropriate algorithms have been developed for the detection of fires using for example infrared sensors (Fuchetti, 1994) or NOAA AVHRR images (Illera, 1993). Geographical Information Systems have found a new area of application in forest fires. These systems integrate database management with remote sensing data and estimation of fire hazard (Galtie, 1993) and can even provide a simulation of fire growth using modular dynamic models (Vasconcelos, 1993).

Numerical models have been developed for predicting fire spread and behaviour, which can readily be integrated with GIS technology. Such models are the BEHAVE model (Rothermel, 1972) which is widely used in the USA, the CFFB model of Canada and IGNITE (Australia). Fire development using Huggen's principle has also been reported (Andre, 1994), where forest fire spread was described in the micro, local and global space-time scales. Turbulent fluid flow calculations have been reported (Lopes, 1994) where wind is calculated using the SIMPLEC procedure. Spread rate is determined using a combination of Rothermel's model, a formulation of fire shape and an algorithm for simulating fire propagation faster than real-time.

A computer based system has been developed that is capable of providing information useful to the co-ordinator of forest fire fighting units, so as to dispatch his units with efficiency and safety in mind. The system consists of a GIS with information on landscape features, where the AIOLOS-F forest fire simulator has been incorporated, capable of predicting forest fire front development faster than real time. The present model makes no use of empiricism but instead solves the physics of the problem.

One of the advantages of the method is that the wind field and the fire spread equations are solved simultaneously and are allowed to interact. A further development of the system could allow the integration of remote sensing techniques that would provide data for updating maps of land cover, plus real-time information on the ignition points of a fire.

2. DESIGN AND IMPLEMENTATION OF THE FOREST FIRE FORECASTING SYSTEM

The forest fire forecasting system prototype has being developed on an HP-Unix platform using the GDS (Graphic Data System) commercial GIS. The system consists of five major components:

- Input Data: the input data required by the system,
- GDS Software Package: the GIS software package,
- AIOLOS-F: the real-time simulator for forest fires integrated in the system,
- Output Data: the output products of the system,
- User Environment: the user-friendly interfaces.

These components linked together form the system architecture as illustrated in Fig.1. The following Subsections present these components in more detail.

2.1 Input Data

The input data required by the forest fire forecasting system fall into four categories a) geographic data, b) fire data, c) meteorological data, and d) other data/parameters. Geographic data should be available before the fire, so that the geographic database is built, whereas the rest of the data are made available during the fire and hence they are real-time data.

Geographic Data (data in batch mode)

Geographic data describe the topography, vegetation, hydrology, roads, service locations, and other infrastructure information of the area under examination. These data (geometry and attribute values) are processed and organised in an appropriate manner within the geographic database provided by the GDS software package. Geographic data are captured through measurements and existing digital maps and databases, or extracted from existing paper maps (digitisation process) and satellite/airborne images. The GDS software package provides the database builder with several tools to exploit a wide variety of data sources. Currently, data have been imported from both paper maps and other GIS systems, having first expressed this data in DLG format.

Fire Data (real-time data)

Fire data provide the system with information regarding the initial location(s) of the fire and the date and time of ignition. The initial location(s) are inserted in the system either graphically, i.e. using the mouse of the computer and clicking in the appropriate locations on a graphical display of the area under examination, or in a text mode, i.e. typing the co-ordinates of these locations referred to in an adopted cartographic projection system.

Meteorological Data (real-time data)

Meteorological data describe the weather conditions during the fire. These data are required by the fire simulator in order to forecast the fire spread. Meteorological data concern temperature, wind velocity and direction, and humidity of the wider area under examination. These data are inserted in the system by typing their values in the fields of a user-friendly form.

Other Data/Parameters (real-time data)

These data determine the values of several parameters which affect the processing of the fire simulator. They include the time step of successive predictions (i.e. every 20 minutes since fire ignition), the window on the area under examination considered for the simulation, etc. These data are inserted in the system by typing their values in the fields of a user-friendly form, which initially accommodate user-defined default values.

2.2 GDS-GIS System

The GDS is the GIS platform on which the application is being developed. It consists of five components from the application point of view (Fig.1.): a) input interfaces, b) data processing, c) geographic database, d) AIOLOS-F interface, and e) display and monitoring (i.e., output interfaces).

Input Interfaces

The input interface assists the communication between the user and the system. Specifically, it provides the former with a series of facilities, through menus, buttons and forms, to insert new data or update existing data residing in the system database. The diversity of input data types is examined in Section 3.1.

Data Processing

Several operations should be performed on input data in order to store them appropriately in the geographic database. These operations include: projection transformations, format transformations, raster images registration, data extraction from satellite images/aerial photographs or scanned paper maps, generalisation, interpolation, editing, error detection and elimination, topology building, feature coding, symbol/style selection, etc. The GDS software package provides several tools to the users and database builders for performing the desired operations. Part of the data processing may be transparent to the end-users.

Geographic Database

The geographic database is the repository of geographic features. Geographic features to populate the database consist of four components:

1. Feature Number (ID): unique numbers associated to the geographic features for identification purposes. These numbers are generated by the system.
2. Feature Code: the type of the entities within the geographic environment (i.e., building, woodland, lake, etc.). The coding scheme adopted in MEFISTO prototype has been based on the standards for the classifications of topographic data proposed by the Canadian Council of Surveying and Mapping (CCSM).
3. Geometry: the shape and location of the geographic features expressed through a set of co-ordinates.
4. Attribute Data: the thematic information associated to the geographic features (i.e., fuel loading, etc.).

The GDS software package provides all the required mechanisms to assist the efficient representation of geographic features in the database, in a way that is transparent to the end-users.

AIOLOS-F Interface

The AIOLOS-F interface assists the communication of the system database with the fire simulator and as a consequence the integration of the latter in the forest fire forecasting system. The AIOLOS-F interface establishes a link (set up and maintained by a number of External Program Interface routines), between the GDS software package and the external program, through which messages and data are exchanged.

Display and Monitoring

It is the output interface of the system. Therefore it assists the display of the system output in a way that is convenient and understandable to the end-users. The system output products take several forms which are presented in Section 2.4.

2.3 AIOLOS-F

AIOLOS-F is the forest fire simulator of the system. It is a program written in the FORTRAN programming language which communicates with the GDS software package through the external program interface (EPI module).

2.4 Output Data

The system output products take several forms: maps, tables, text. All these can be obtained and stored (i.e., maintain history) either in digital form (i.e., graphical displays or files) or in hard-copies (i.e., print-outs). System output products fall into three categories: a) predicted fire-front and temperatures, b) predicted wind parameters, and c) other output data (e.g., pressure and density field, etc.).

Fire-Front

The monitoring of the simulated fire-front is of particular importance to the users of the system. The successive positions of the simulated fire-front are derived from the predicted temperature field of the area under examination in the pre-defined time steps (Section 3).

Wind Parameters

The notion of the simulated wind parameters may help the users of the system to fight the fire effectively. The successive values of the simulated wind parameters of the area under examination in the pre-defined time steps (Section 3.1) are displayed.

Other Output

The system may provide the users with several other output products such as: pressure and density field, effective dynamic viscosity, mixture fraction, enthalpy, etc. In addition the users may browse in the geographic database and perform queries (i.e., information retrieval).

2.5 User Environment

The user interfaces assist the communication between the user and the system. Three subsystems (modules) are being developed to meet the requirements of the end-users. All three modules provide a user-friendly menu-driven environment. The first module allows the user to create a new or update an existing database. The second module allows the user to view the geographic database, browse and perform queries, as well as view old fires which are kept in archives (history). Finally, the third module allows the user to run the fire simulator for a new fire and view the results, which can be kept in the archives, if desired, for future examination.

These modules can be executed separately using appropriate commands from the UNIX command line. Permissions/passwords may be established to prevent the use of one or more modules from unauthorised users. For instance, the module that updates the database should be available to a limited number of persons who are responsible for the consistency of the database.

3. DESCRIPTION OF THE MATHEMATICAL MODELLING INCORPORATED IN THE AIOLOS-F SIMULATOR

The ignition and spread rate of a forest fire depends on a number of factors, whose interactions are very complex. These factors can be grouped into fuel properties (Rothermel, 1972) like calorific value, reaction intensity, fuel moisture and spatial non-homogeneity, weather conditions (Carrier, 1991) like wind, atmospheric humidity, stability and temperature and landscape slope/ complexity.

The governing equations that are incorporated in the simulator are:

1. the 3D mass-consistent equation of the potential flow perturbation Φ,
2. the unsteady, time-averaged Navier-Stokes (Reynolds) equation along the vertical direction (w-momentum equation),
3. the unsteady enthalpy h conservation equation, and
4. the unsteady mixture-fraction of the conservation equation.

The flow is considered turbulent when solving the w-momentum equation. A zero-equation turbulence closure scheme suitable for atmospheric flows has been adopted. Three types of boundaries are distinguished : the ground (lower boundary), the upper boundary and the lateral boundaries. The perturbation potential Φ is set constant on all lateral boundaries and its normal derivative is set to zero on the ground and on the top boundary. No initial condition is required, since the mass-consistent equation is expressed in steady state.

For the vertical velocity component w a zero derivative is set on the lateral boundaries. The top boundary being considered high enough from the ground w is set to zero there. On the ground two different cases are considered: a) for no fire zones w is set to zero and b) for fire zones w is set to a constant value w_g. This w_g velocity corresponds to an upwind draft due to the emission of hot, gaseous products of combustion at the fire locations, considering that all combustible material lies below the first grid surface above ground level. As an initial condition w is set to zero everywhere in the computational domain (fire not yet ignited).

The enthalpy h and mixture-fraction m_f are set constant on the top boundary ($h = H_{ref} = 0.3$ MJ/kg and $m_f = 0$ respectively) and their derivatives are set to zero on the lateral boundaries. On the ground h=Href and m_f everywhere except from fire locations, where $h = H_{fuel}$ and $m_f = 1$. H_{fuel} is the calorific value of fuel in J/kg (for white pine Hf_{uel} varies from 17 to 19 MJ/kg depending on the moisture content). The fuel loading is another parameter that needs to be defined for modelling the fire spread. Initial conditions for enthalpy and mixture-fraction are set to: $h = H_{ref}$ and $m_f = 0$ (fire not yet ignited). Equations are discretised by the finite-volume method, applying the hybrid scheme for the convection terms and the SIMPLE algorithm for linking w-velocity and pressure.

For each time-step the velocity components are calculated through the equations of mass continuity and w-momentum and then the enthalpy and mixture-fraction are calculated through their respective equations. Then the obtained enthalpy field is used to calculate the temperature and the density fields. The wind-field calculation is repeated to update the values of u, v, w. The same iterative procedure is carried out for one time instant t_n until convergence is achieved and then the next instant t_{n+1} is considered. The term linking two successive instants is :

$$\frac{EA}{Et\,Dt} = \frac{An - 1}{}$$

4. RESULTS, CONCLUSIONS

Geographic and vegetation data have been imported in the developed system for regions of Greece, Italy and Portugal. The resolution and accuracy of this data varied according to that of the data source, with the cost of this data varying accordingly. In the case of Italy for example, the vegetation was determined from multispectral Landsat images with a resolution of 80m, while hypsography was obtained from 1:25,000 paper maps. In the case of Greece, vegetation and hypsography plus all other information was obtained from 1:50,000 paper maps which were 7 years old, where vegetation is presented in five categories without any indication on fuel density, etc. This situation

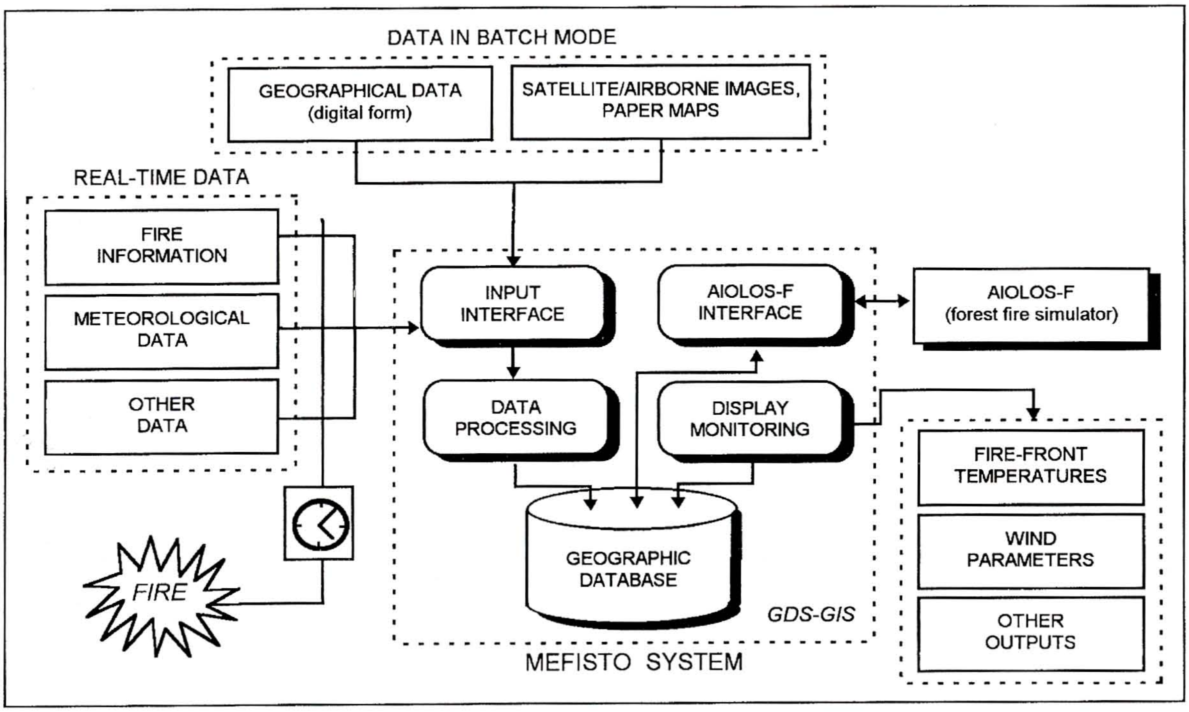

Figure 1 - The system architecture

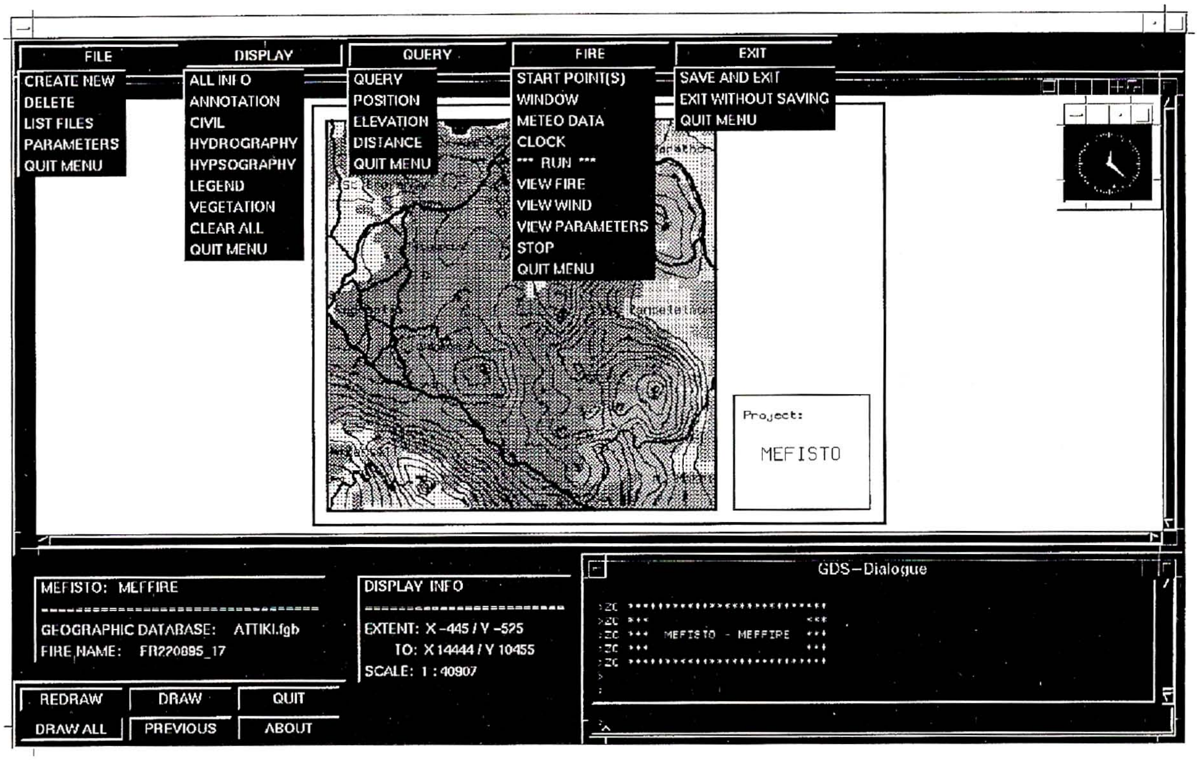

Figure 2 - A typical screen of the system

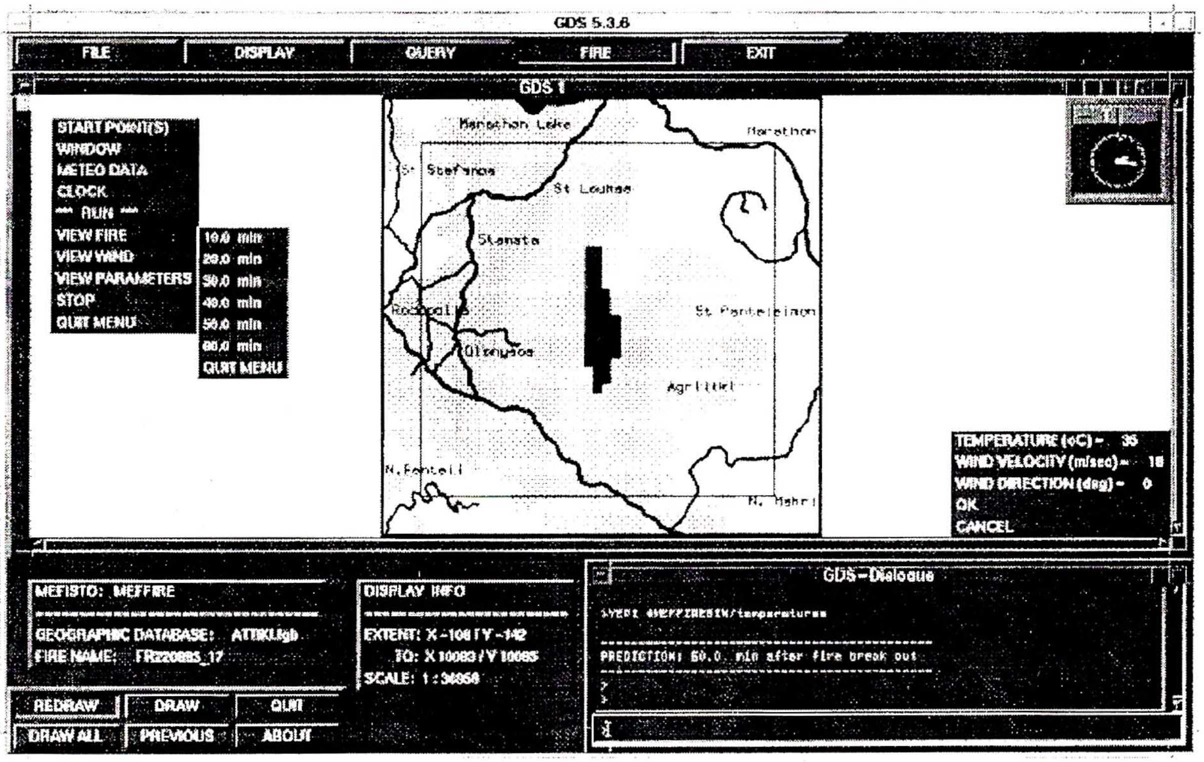

Figure 3 - The predicted fire front at 30 and 50 minutes after fire break out

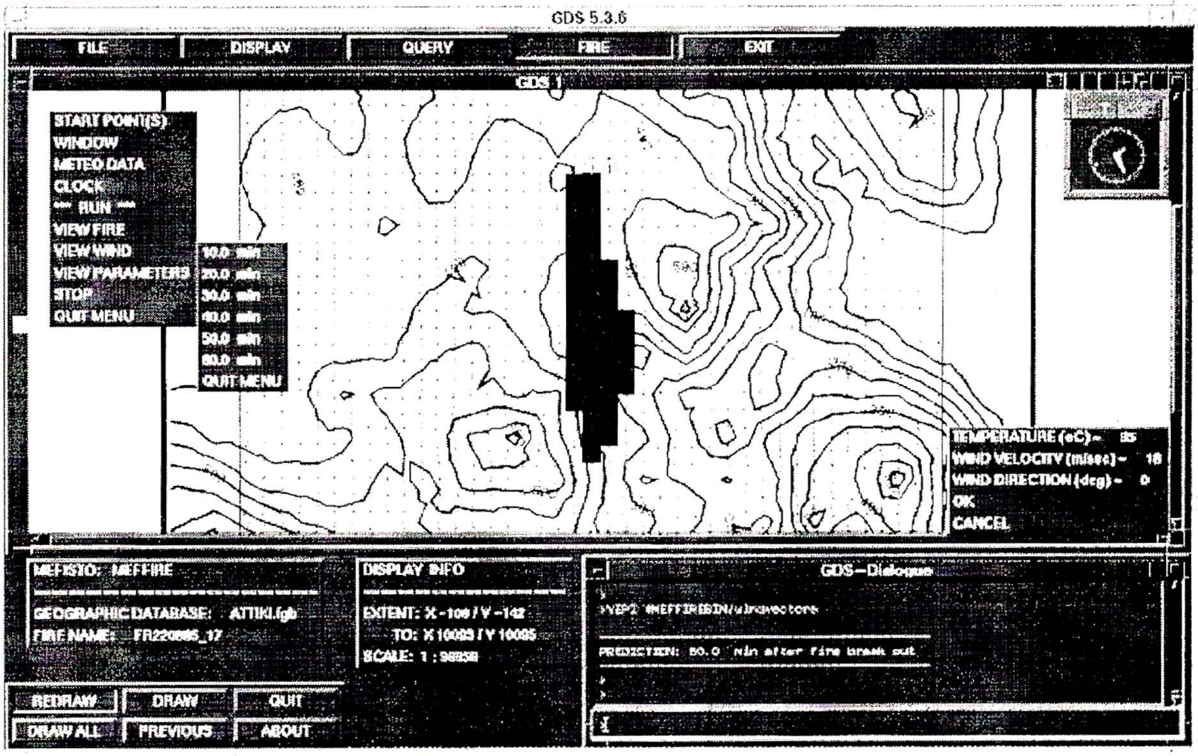

Figure 4 - The predicted position of fire front and wind field at 10m a.g.l. (50 minutes after fire break out)

could be improved though the incorporation of remote sensing techniques like NOAA AVHRR or Landsat/SPOT that would provide data for updating maps on dryness and land cover, plus real-time information on the ignition points of a fire.

Figure 2 presents a typical working screen of the developed system. This screen consists of a) a graphics area which displays pictures generated by the system; b) a dialogue area which assists the communication between the user and the system; c) a couple of status menus that display information about the current session (e.g., file names, map scale and extents, etc.); d) a clock; and e) a series of buttons in pull-down menus that performs all tasks desired by the user.

Figure 3 depicts the ignition points (white area), the area burned 30 (grey area) and 50 (black area) minutes after ignition, as predicted by the forest-fire simulator, for a test area of Attiki, Greece and a northern wind.

Figure 4 shows a detail of the region of the fire, where the wind velocity vectors at 10m a.g.l. and the height contours are displayed. Given that field data on the actual development of a wild fire are hard to get, the model has till now been compared with the model of Rothermel (Rothermel, 1972) where for an upper-air speed of 18m/s, leading to 10m/s near the ground, the spread rate was 1m/sec. In the context of the project in which this system is being developed, it is intended to compare the model with actual field data which are currently being collected.

A GIS-based forest fire management information system has thus been developed that provides the user with information useful in fire fighting, like landscape features, and predicted position of a fire front. The forest fire simulator that has been incorporated, tackles the physics of the complex forest fire phenomenon, in a way that allows the computations to be faster than real time. The simulator is suitable for modelling crown fires in complex terrain, covering an area of up to 10km (mesoscale model).

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