EUFIRELAB

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EUFIRELAB:

Euro-Mediterranean Wildland Fire Laboratory, a “wall-less” Laboratory for Wildland Fire Sciences and Technologies in the Euro-Mediterranean Region

Deliverable D-03-02

Behaviour modelling of wildland fires: Inventory and technical characteristics of wildland fire numerical simulation codes (First version)

Collective work moderated by Dominique MORVAN

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SUMMARY

This document inventories ten codes of behaviour models of wildland fires and summarises their main characteristics:

- the main physical models included in the code,
- the numerical resolution methods and physical models
- the physical inputs
- the physical outputs
- the development tools and platforms, and
- the persons to contact

An example of simulation is given for each code

GLOSSARY

None

LIST OF ASSOCIATED DOCUMENTS

None

1 FIRESTAR-2.0.

1.1 WILDFIRE MODELLING CLASSIFICATION

Complete Physical Approach

1.2 MAIN PHYSICAL MODELS INCLUDED IN THE CODE

Multiphase Reactive Fluid Flow,
Turbulence, Combustion, Heat and Mass Transfers,
Soot production, Radiation heat transfer,
Decomposition of the vegetation (Drying, Pyrolysis, Charcoal combustion),
Heterogeneous structure of the vegetation (FIRESTAR protocol),

1.3 NUMERICAL RESOLUTION METHODS AND PHYSICAL MODELS

Unsteady Finite Volumes (FV) Method (Gas phase),
3rd Order QUICK scheme (space), 2nd Order Euler (time),
Flux Limiting Strategy (ULTRA-SHARP),
4th Order Runge-Kutta Method (Solid phase),
2D plane (direction of fire propagation X, vertical Z) geometry,
Space range resolution (5 cm-200 m),
Dynamics Adaptative Mesh Algorithm,
Turbulence: k- RNG,
Combustion : Eddy Dissipation Turbulent Combustion model,
Radiation : Discrete Ordinate Method (DOM),

1.4 PHYSICAL INPUTS

Structure (species, space distribution), physical properties (Surface Area/Volume ratio, density, shape) and state (moisture content) of the vegetation,

External flow conditions (wind speed before fire ignition, air moisture content, ambient air temperature …),

Slope of the terrain,

1.5 PHYSICAL OUTPUTS

Gas mixture (air + pyrolysis + combustion products) fluid flow (velocity vector field, pressure, turbulence kinetics energy …),

Gas mixture state (composition, temperature, enthalpy, soot concentration, radiation intensity, total absorption …),

Vegetation state (composition, temperature, fuel load, radiation and convection heat transfers, …),

Rate Of Spread (ROS) evaluated from the time evolution of the position of the pyrolysis front,

Rate Of Mass Loss integrated though the fuel layer,

Effective Line Fire Intensity evaluated from the real fuel consumption,

Visual flame geometry (contour, height) evaluated from temperature field in the gas phase (we can also extract the flame geometry from the energy released by radiation),

1.6 DEVELOPMENT TOOLS AND PLATFORMS

FORTRAN 77
Personal Computer (INTEL, AMD processors)
Other platforms (UNIX) can be developed if necessary

1.7 CONTACT

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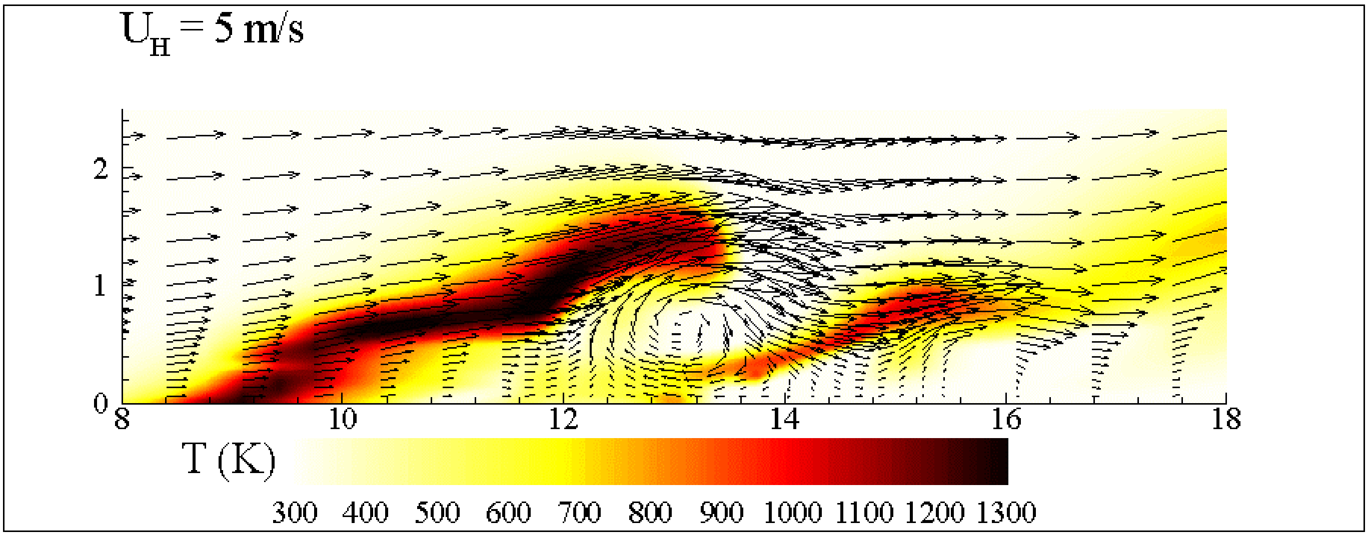

Figure 1-1: Example of simulation
Propagation of a surface fire though a Mediterranean shrub (temperature and velocity field of the gas phase)

2 FIREREGIME-1.0.

2.1 WILDFIRE MODELLING CLASSIFICATION

Cellular automata model of fire regime

2.2 MAIN PHYSICAL MODELS INCLUDED IN THE CODE

Fire spread: probabilistic, influenced by the fuel load of the cell and meteorology
Vegetation dynamics: deterministic linear increase of fuel load until a maximum is reached
Fire management: fire suppression and prescribed fire
Spatial resolution: 1 ha
Time resolution: 1 year

2.3 NUMERICAL RESOLUTION METHODS AND PHYSICAL MODELS

Montecarlo search to find behavioural parameter sets, that is, those who conform with fire regime data (n fires per year, annual area burnt, and distribution of number of fires and area burnt among fire size classes)

2.4 PHYSICAL INPUTS

None. The model is conceptual. Nevertheless inputs reproduced likely scenarios for meteorology and vegetation dynamics in Mediterranean regions

2.5 PHYSICAL OUTPUTS

Number of fires per year (total and per fire size class)
Area burnt per year (total and per fire size class)
Area burnt per year in prescribed fires

2.6 DEVELOPMENT TOOLS AND PLATFORMS

Java
Windows, MacOs, Linux

2.7 CONTACT

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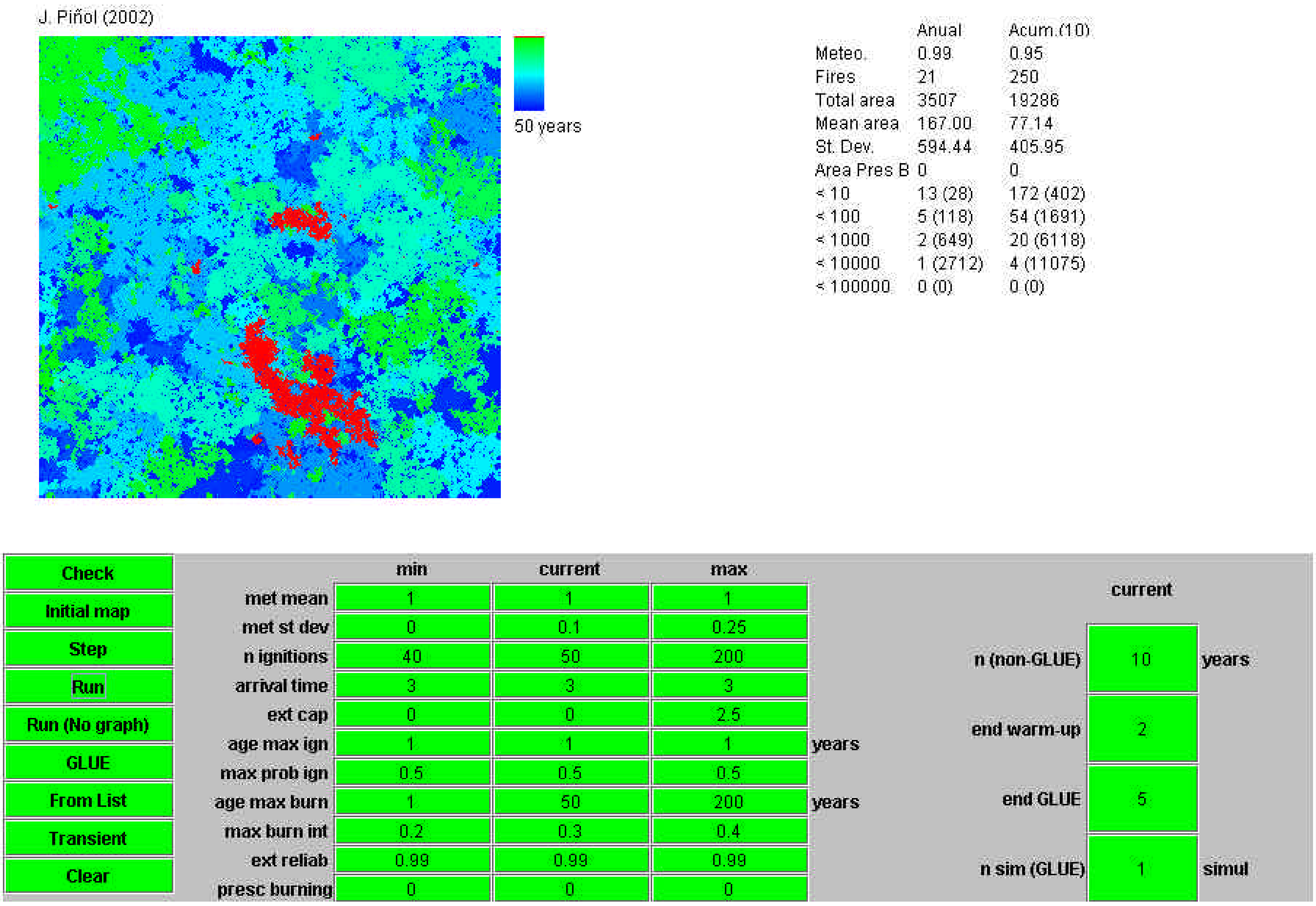

	Anual	Acum.(10)
Meteo.	0.99	0.95
Fires	21	250
Total area	3507	19286
Mean area	167.00	77.14
St. Dev.	594.44	405.95
Area Pres B	0	0
< 10	13 (28)	172 (402)
< 100	5 (118)	54 (1691)
< 1000	2 (649)	20 (6118)
< 10000	1 (2712)	4 (11075)
< 100000	0 (0)	0 (0)

	min	current	max	
met mean	1	1	1	
met st dev	0	0.1	0.25	
n ignitions	40	50	200	
arrival time	3	3	3	
ext cap	0	0	2.5	
age max ign	1	1	1	years
max prob ign	0.5	0.5	0.5	
age max burn	1	50	200	years
max burn int	0.2	0.3	0.4	
ext reliab	0.99	0.99	0.99	
presc burning	0	0	0	

	current	
n (non-GLUE)	10	years
end warm-up	2	
end GLUE	5	
n sim (GLUE)	1	simul

Figure 2-1 :Example of simulation : The area cover *ca*. 100,000 ha of flat terrain.
Colours indicate the age of vegetation (and its fuel load); red colour indicates fires produced in the last year

3 SPREAD SECTION2 WP 2.1

3.1 WILDFIRE MODELLING CLASSIFICATION

Detailed Physical Approach

3.2 MAIN PHYSICAL MODELS INCLUDED IN THE CODE

Multiphase Reactive Fluid Flow,
Turbulence, Combustion, Heat and Mass Transfers,
Radiation heat transfer,
Decomposition of the vegetation (Drying, Pyrolysis, Charcoal combustion),
Porous description of the vegetation as a fractal,
Internal porous structure of the fuel.

3.3 NUMERICAL RESOLUTION METHODS AND PHYSICAL MODELS

Unsteady Finite Volumes (FV) Method (Gas phase),
2rd Order QUICK scheme (space), 2nd Order Euler (time),
Flux Limiting Strategy (ULTRA-SHARP),
4th Order Runge-Kutta Method (Solid phase),
3D geometry,
Space range resolution (5 cm-10 m),
Dynamics Adaptative Mesh Algorithm,
Turbulence: k-ε RNG,
Combustion : Eddy Dissipation Turbulent Combustion model,
Radiation : Discrete Ordinate Method (DOM),

3.4 PHYSICAL INPUTS

Structure (porosity, Surface/Volume), physical properties (density, moisture, heat properties, permeability) and state (moisture content) of the vegetation,
External flow conditions (wind speed before fire ignition, air moisture content, ambient air temperature …),
Slope of the terrain,

3.5 PHYSICAL OUTPUTS

Gas mixture (air + pyrolysis + combustion products) fluid flow (velocity vector field, pressure, turbulence kinetics energy …),
Gas mixture state (composition, temperature, enthalpy, soot concentration, radiation intensity, total absorption …),
Vegetation state (composition, temperature, fuel load, radiation and convection heat transfers, …),
Rate Of Spread (ROS) evaluated from the time evolution of the position of the pyrolysis front,
Rate Of Mass Loss integrated though the fuel layer,
Effective Line Fire Intensity evaluated from the real fuel consumption,
Visual flame geometry (contour, height) evaluated from temperature field in the gas phase (we can also extract the flame geometry from the energy released by radiation),

3.6 DEVELOPMENT TOOLS AND PLATFORMS

FLUENT, C
Personal Computer (INTEL, AMD processors)
Other platforms (LINUX)

3.7 CONTACT

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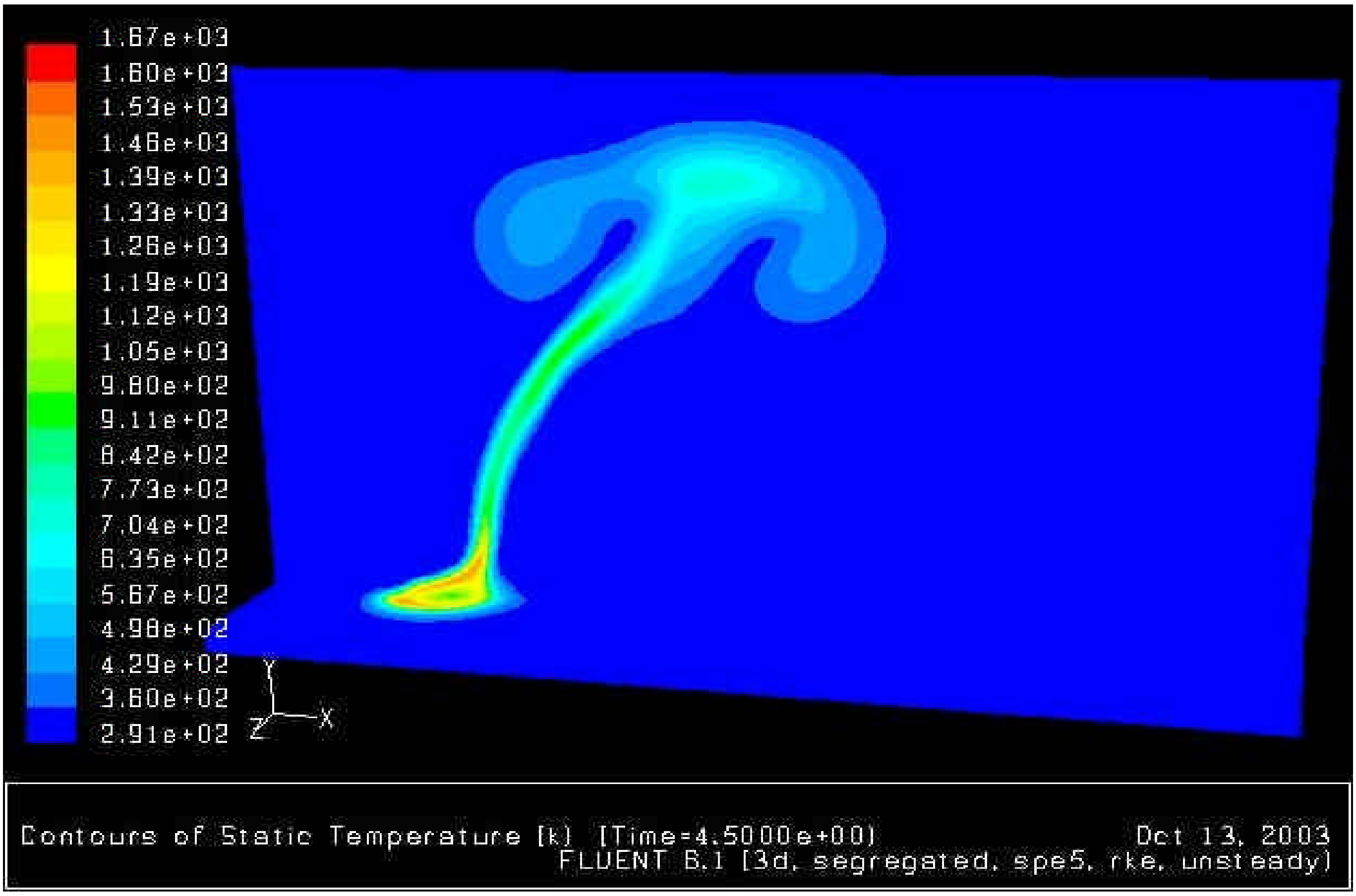

Figure 3-1 : Example of simulation : Ignition of the litter (contour of temperature)

4 SPREAD SECTION2 WP 2.1

4.1 WILDFIRE MODELLING CLASSIFICATION

Reaction-Diffusion propagation model

4.2 MAIN PHYSICAL MODELS INCLUDED IN THE CODE

Drying and pyrolysis of vegetation,
- Energy equation of the solid phase,
- Radiation heat transfer

4.3 NUMERICAL RESOLUTION METHODS AND PHYSICAL MODELS

TVD scheme + limiter
4th Order Runge-Kutta Method,
2D plane X, Y (vertical absent),
Space range resolution (100 m-500 km),
Dynamics Adaptative Mesh Algorithm,

4.4 PHYSICAL INPUTS

Spatial distribution of vegetation, moisture content,
External flow conditions (wind speed before fire ignition, air moisture content, ambient air temperature …),
Terrain,

4.5 PHYSICAL OUTPUTS

Temperature of the solid phase,
Rate Of Spread (ROS) evaluated from the time evolution of the position of the pyrolysis front,
Rate Of Mass Loss integrated though the fuel layer,
Effective Line Fire Intensity evaluated from the real fuel consumption.

4.6 DEVELOPMENT TOOLS AND PLATFORMS

FORTRAN 90, parallelisation MPI
Personal Computer (INTEL, AMD processors)
Other platforms (LINUX)

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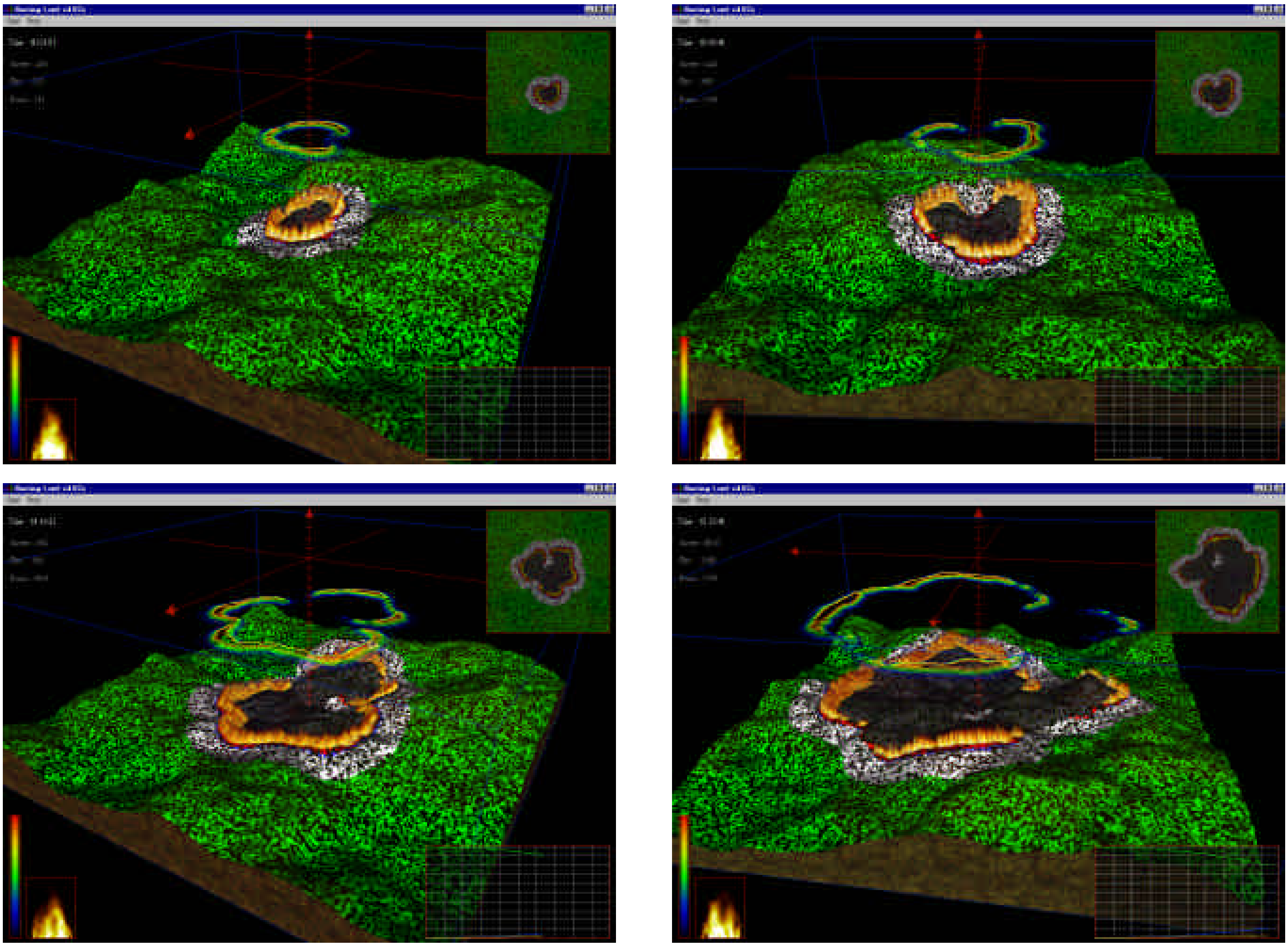

Figure 4-1 :Example of simulation : Propagation of a fire on the ground

5 FIRESTATION

5.1 WILDFIRE MODELLING CLASSIFICATION

Fire propagation and wind field simulation – semi empirical approach.

5.2 MAIN PHYSICAL MODELS INCLUDED IN THE CODE

Fire rate of spread: based on Rothermel's surface fire spread (ROTHERMEL, 1972).

Fire shape: Simple ellipse model (Alexander, 1985) or double ellipse (ANDERSON, 1983) if wind speed at mid flame is lower than 0.2 m/s

Fire growth: raster approximation. Fire growth is a process of contagion between burning and non-burning cells. The algorithm followed is based on Dijkstra's dynamic programming algorithm

Wind simulation: two models are implemented: NUATMOS, a kinematic model (ROSS et al., 1988) and CANYON, a full Navier-Stokes solver (LOPES et al., 1995)

Fire Weather Index: The system allows to (1) have a broad assessment of large-scale fire potential through the evaluation of the daily and spatial variation of the fire danger index and (2) estimate the moisture content of dead and live fine fuels through empirical relationships.

5.3 NUMERICAL RESOLUTION METHODS AND PHYSICAL MODELS

Fire propagation and wind simulation are limited to the resolution (cell size) of the input raster maps (DTM and vegetation).

NUATMOS is a kinematic model that solves the Fluid Dynamics continuity equation. Some degree of adjustment between the horizontal and vertical wind components allows simulation of atmospheric stability.

CANYON is a full Navier-Stokes solver with a k- turbulence model.

5.4 PHYSICAL INPUTS

Fire propagation: terrain characteristics (Digital Terrain Model); wind data (speed and direction) and fuel characteristics (physical characteristics such as load by classes, s/v ratio, heat content, extinction moisture, fuel depth, fuel moisture)

Wind simulation: terrain characteristics (DTM); wind speed and direction at known locations (x, y, z)

5.5 PHYSICAL OUTPUTS

3d Windfield values

Fire Risk Mapping (FWI and it's components, namely FFMC, DMC, DC, ISI and BUI);

Fire spread simulation: characteristics (graphical and numerical) in each cell, namely fire rate of spread, linear intensity, flame length, energy released.

5.6 DEVELOPMENT TOOLS AND PLATFORMS

Written in MDL, a specific C language of Microstation® (Bentley CAD software) that has built-in subroutines for the design of window-based interfaces, generation of visualization elements in the 3D space, on top of the usual mathematical capabilities of the C language. The wind models are self-contained Fortran codes, which run as external programs. Requires MicroStation® to run.

Stand alone development is being considered.

5.7 CONTACT

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5.8 REFERENCES

ALEXANDER, M.E. (1985) - "Estimating the length-to-breadth ratio of elliptical forest fire patterns", in Proceedings of the eighth conference on fire and forest meteorology. Soc. Am. For., pp. 287-304, Bethesda, Maryland.

ANDERSON, H.E. (1983) - "Predicting Wind-Driven Fire Size and Shape", USDA-FS, Ogden UT, Research Paper INT-305.

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ROSS, D.G., SMITH, I.N., MNINS, P.C. and FOX, D.G. (1988) - "Diagnostic wind field modeling for complex terrain: Model development and testing", Journal of Applied Meteorology, Vol. 27, pp. 785-796.

ROTHERMEL, R.C. (1972) - "A Mathematical Model For Predicting Fire Spread in Wildland Fuels", USDA Forest Service Research Paper, INT-115, Ogden UT.

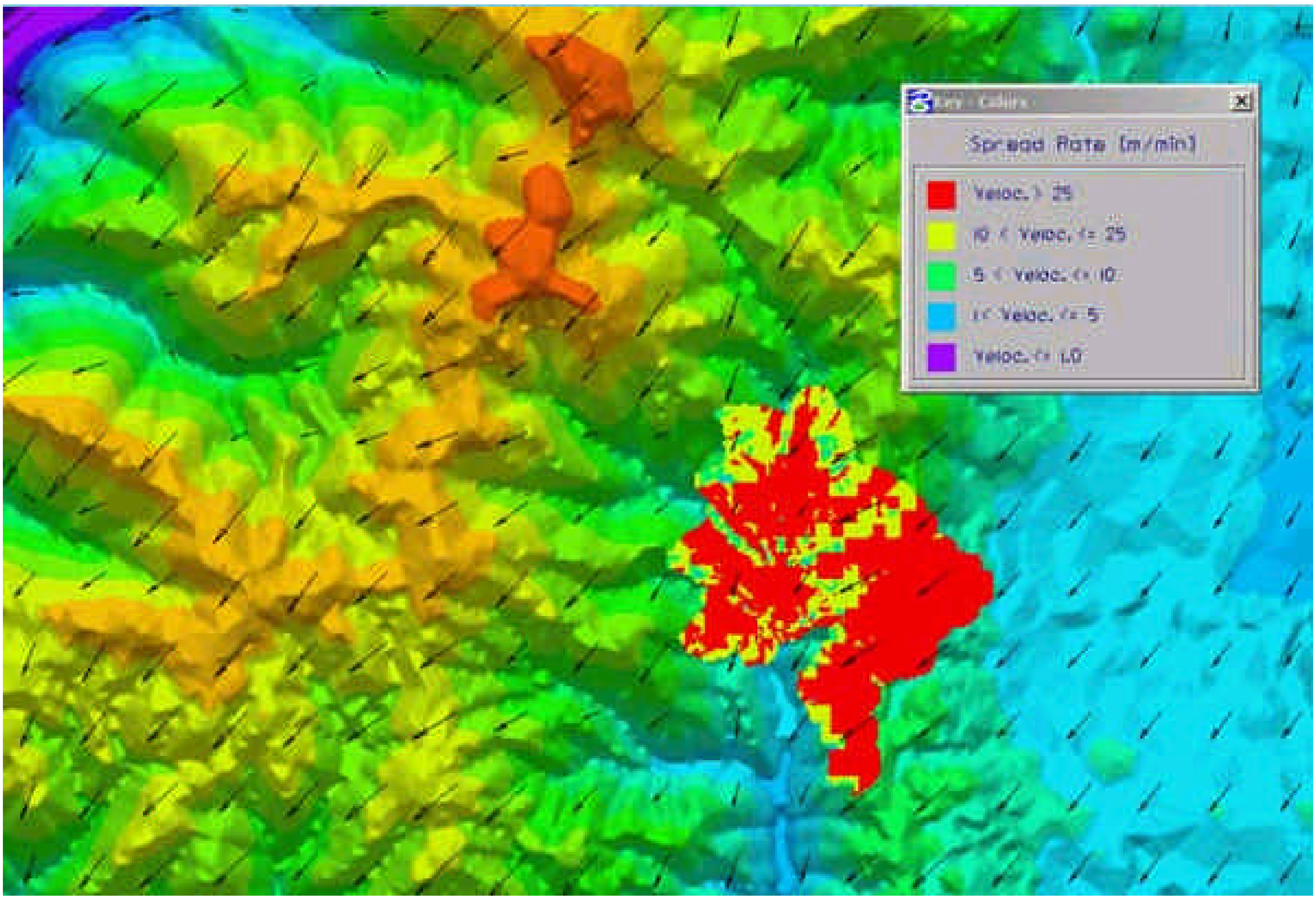

Figure 5-1 : Fire spread and wind field in a mountainous region of central Portugal.
Colours in fire region relate to fire spread rate.

6 FIRE LINE ROTATION MODEL (FRM)

6.1 WILDFIRE MODELLING CLASSIFICATION

Semi-empirical

6.2 MAIN PHYSICAL MODELS

Heat transfer due to convection; feedback effect on the chemical reaction.

6.3 NUMERICAL METHODS AND PHYSICAL MODELS

The evolution of a linear flame front in a homogeneous fuel bed in a slope, for arbitrary values of the initial orientation of the fire front is studied.

It is shown that, with the exception of initially horizontal or down slope propagating fire lines, the propagation is not stationary.

In its movement the fire front rotates, tending to become parallel to the slope gradient direction.

The concept of fire line rotation as a tool to interpret and describe the evolution of a fire front is presented.

Experimental results developed at a laboratory scale in a 30º slope are presented to support it.

Some insight about the role played by natural convection induced by the fire is provided.

A model using the concept of fire line rotation is proposed to predict the evolution of a fire front.

Its application to the case of a point ignition fire in a slope is presented.

6.4 PHYSICAL INPUTS

Terrain slope; reference wind flow velocity; basic rate of spread of the fuel bed.

6.5 PHYSICAL OUTPUTS

Temporal evolution from a linear fire front in a slope or from a point ignition fire in a slope.

6.6 DEVELOPMENT TOOLS AND PLATFORMS

This model is being developed in order to incorporate arbitrary conditions of wind and slope, as well as arbitrary terrain and fuel bed changes.

6.7 CONTACT

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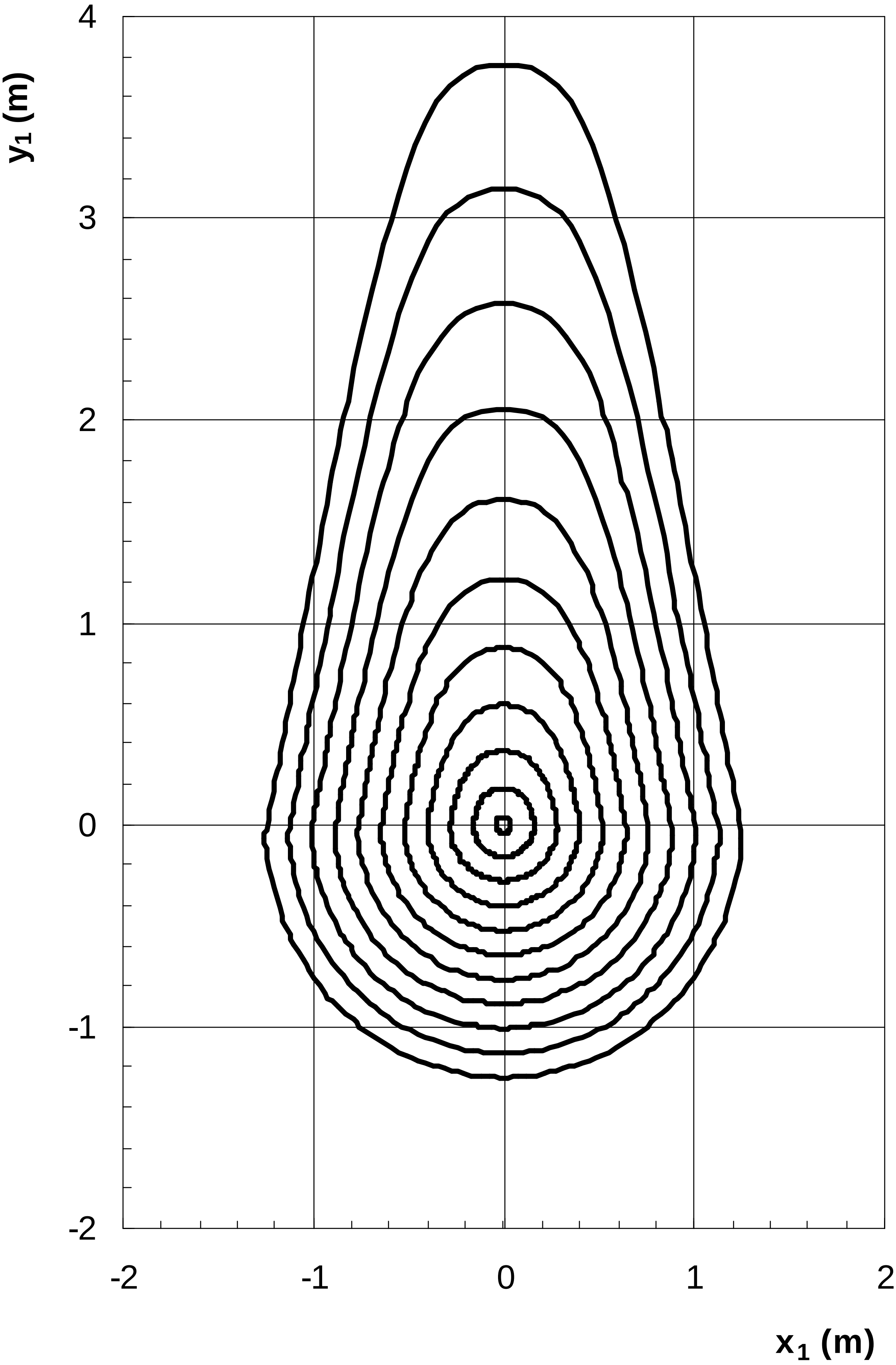

Figure 6-1 : A typical output of the FRM: prediction of a point-ignition fire in a slope.

7 INCENDIU 1.0

7.1 WILDFIRE MODELLING CLASSIFICATION

Reaction-Diffusion propagation model

7.2 MAIN PHYSICAL MODELS INCLUDED IN THE CODE

Energy equation for the fuel layer
Radiant and convective heat transfers
Gas flow in the fuel layer

7.3 NUMERICAL RESOLUTION METHODS AND PHYSICAL MODELS

Finite-differences schema
4th Order Runge-Kutta Method
2D description along the ground shape
Space range resolution (1 m² - 18 m²) – laboratory scale

7.4 PHYSICAL INPUTS

Spatial distribution of vegetation, moisture content
External flow conditions (wind speed before fire ignition, ambient air temperature …)
Slope
Fuel load

7.5 PHYSICAL OUTPUTS

Temperature of the fuel layer
Rate Of Spread (ROS) evaluated from the time evolution of the position of the pyrolysis front,
Fire front shape
Flame height

7.6 DEVELOPMENT TOOLS AND PLATFORMS

C ANSI,
Personal Computer (INTEL processors)
Other platforms (LINUX)

7.7 CONTACT

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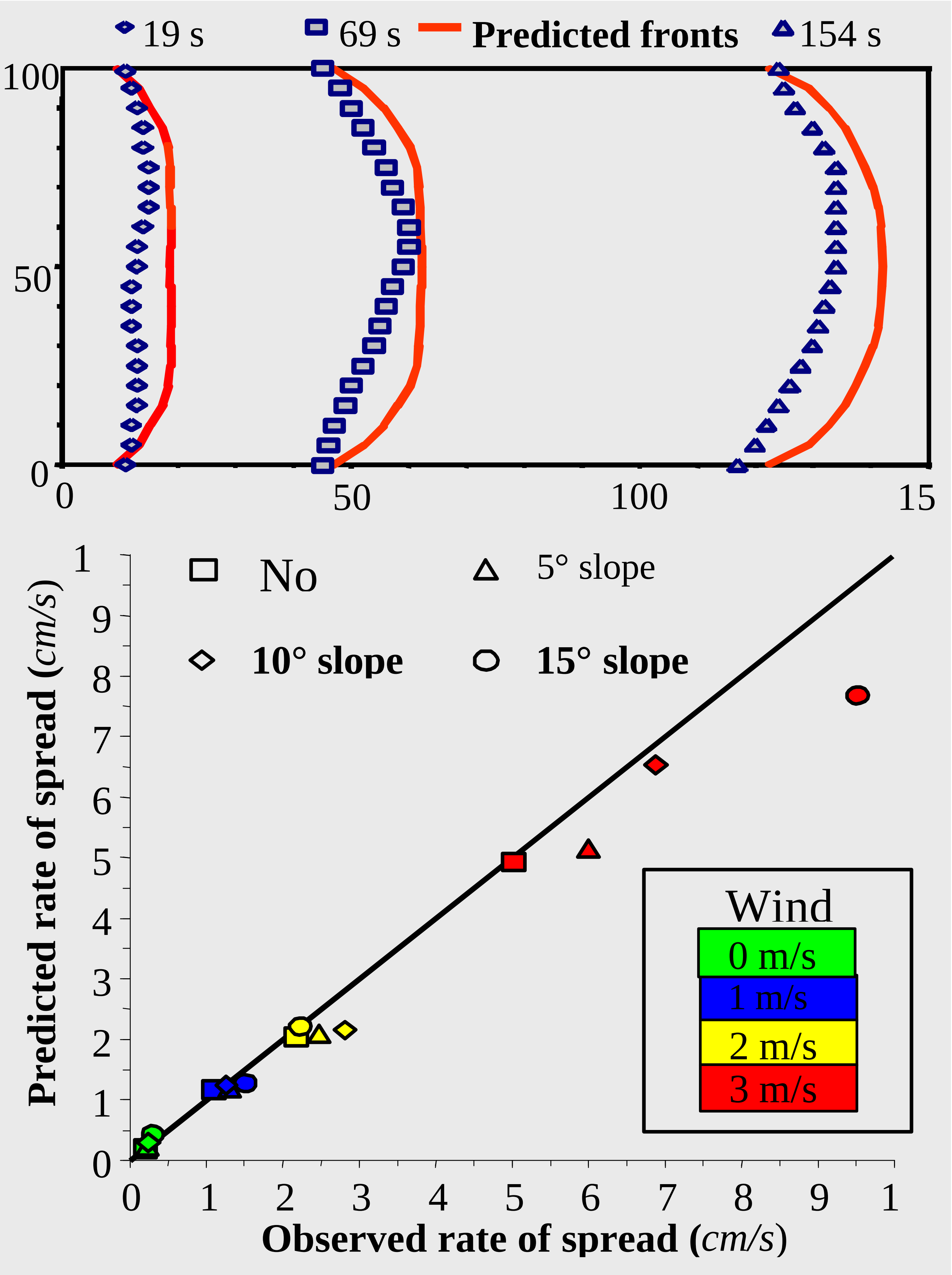

Figure 7-1 : Example of simulations for fire spreads trough pine needle beds
Fire front shape for a 10° slope and no wind conditions
Rates of spread for various slope and wind conditions

8 SPREAD 1.0

8.1 WILDFIRE MODELING CLASSIFICATION:

Incomplete or phenomenological physical approach (cf. D-03-01)

8.2 MAIN PHYSICAL MODELS INCLUDED IN THE CODE

Heat sink sub models (semi empirical): joint sensible heat and pyrolysis, and moisture heating and drying of fuel particles.

Heat flux sub models: radiation from the combustion interface within the fuel bed and the flames, re-radiation of the non-burned fuel particles and radiation extinction coefficients of the fuel bed (physical); convection between the fuel particles and the ambient air (empirical).

Heat source sub models (empirical): estimation of the height of the flames in still air, and of the vertical profile of radiant emissive power of the flames.

8.3 NUMERICAL RESOLUTION METHODS AND PHYSICAL MODELS

Non-standard analytical and numerical methods were specifically developed to solve the model.

The 2D energy equation is solved for the fuel particles ahead of the fire front, with the help of a deformed grid, using four nested iterative cycles, respectively, for: the temperature field, the curved profile of the combustion interface within the fuel bed, an auxiliary rate of spread and the true rate of spread of the fire front.

Numerical integrations are performed with Romberg Method coupled with the Mid Point Rule, and with the Trapezoidal Rule.

8.4 PHYSICAL INPUTS

Properties of the fuel bed (statistically homogeneous): global fuel load and spatial and directional distribution of the fuel particles; fuel particles’ properties: dimensions and form parameters, dry density, ignition temperature, low heat value, moisture quantity.

Properties of the ambient: air temperature, wind speed and slope. (For the moment, the later two properties must be null.)

Properties of the fire front (pre estimated or postulated): radiant effective temperature of combustion interface, combustion mass efficiency.

8.5 PHYSICAL OUTPUTS

Average (steady) properties of the fire front: rate of spread, height of flames, 2D shape of the combustion interface within the fuel bed, mass rate of fuel consumption, fire line intensity.

Non-burned fuel bed (fuel particles): spatial fields of temperature, moisture content and total heat absorbed.

8.6 DEVELOPMENT TOOLS AND PLATFORMS

FORTRAN 90
Personal Computer (PC)

8.7 CONTACT

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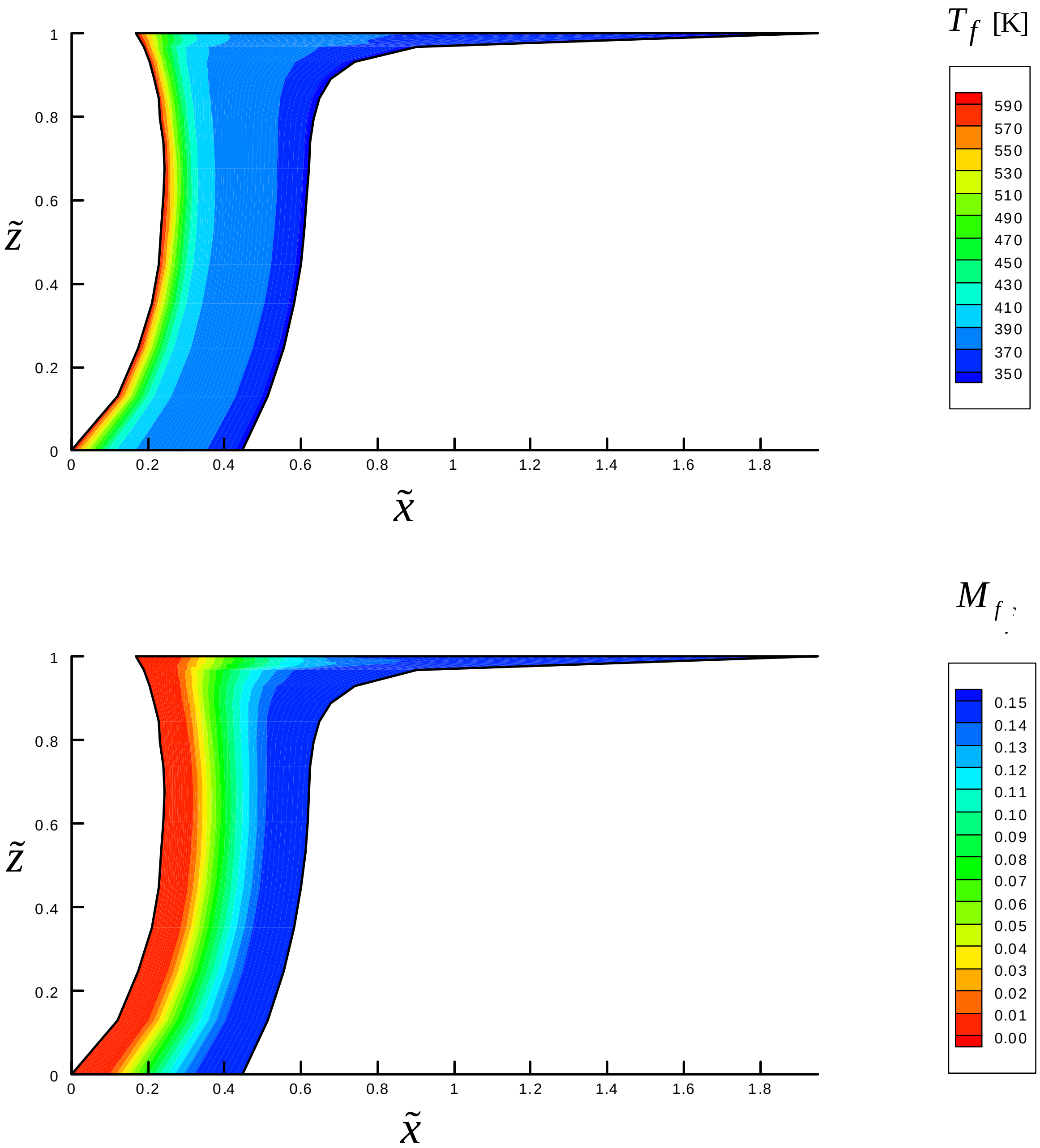

Figure 8-1 : Example of simulation
Outputs of the standard calculation at the test point, for the fields of temperature and moisture content of the non-burned fuel particles throughout the main domain of calculation (hot region).

9 AIRFIRE

9.1 WILDFIRE MODELLING CLASSIFICATION

Smoke dispersion model - Physical Approach

9.2 MAIN PHYSICAL MODELS INCLUDED IN THE CODE

9.2.1 MEMO meteorological model

Three dimensional Eulerian non-hydrostatic prognostic mesoscale model;
Numerical solution of the conservation equations for mass, momentum and transport for scalar quantities (potential temperature, turbulent kinetic energy and specific humidity) in terrain-following coordinates;
Nesting facility, one-way interactive nesting scheme is implemented
Modified sub-routine for energy fluxes and atmospheric heating rate allows the introduction of the fire as a heat source.

9.2.2 Fire model

Based on Rothermel model (spread model of low intensity surface forest fires)
Fire growth simulation: deterministic model based on Huygen’s principle, which uses an elliptical spread at each point of the fire front.

9.2.3 MARS photochemical model

Three dimensional Eulerian model;
Numerically simulates photo-oxidants formation considering the chemical formation process and its transport in the atmospheric boundary layer;
Solves the differential concentration transport equation system in terrain following co-ordinates, with the meteorological variables calculated by MEMO;
Fire emissions model integrated.

9.3 NUMERICAL RESOLUTION METHODS AND PHYSICAL MODELS

9.3.1 MEMO meteorological model

Turbulence: K-theory (0-, 1- or 2-equation turbulence model);
Radiative heating/cooling rate and radiative fluxes : based on emissivity method for long wave radiation and an implicit multilayer method for short wave radiation.

9.3.2 MARS photochemical model

Estimation of fire emissions according to Ward and Radke;
Two chemical mechanisms: EMEP (66 species, 139 photochemical reactions) and KOREM (20 species, 39 photochemical reactions).

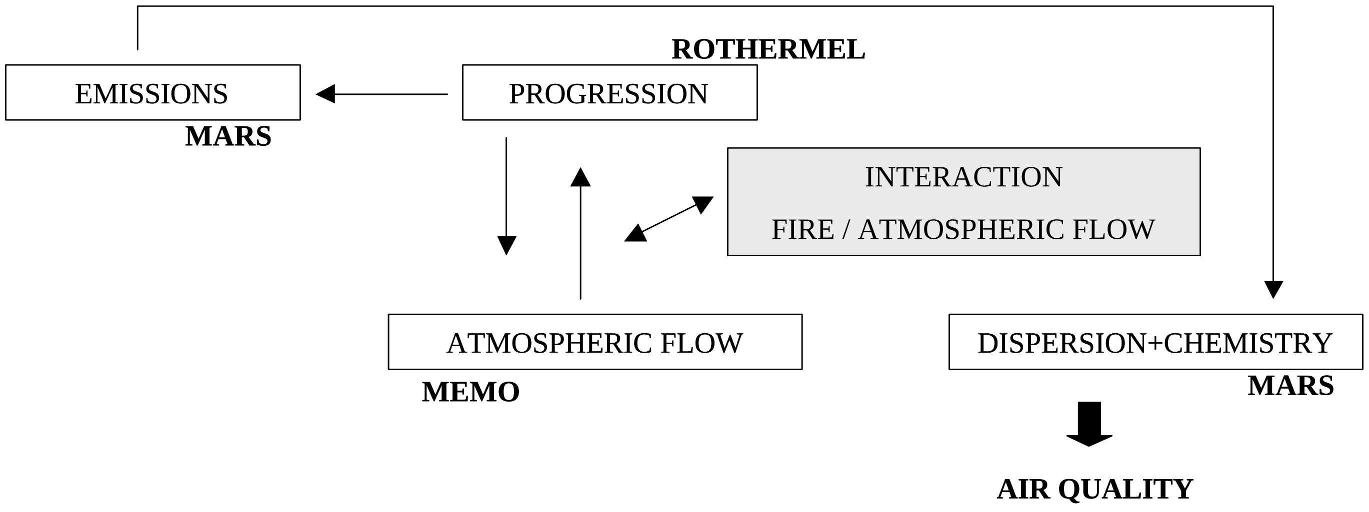

Figure 9-1 : Structure of the model

9.4 PHYSICAL INPUTS

9.4.1 MEMO meteorological model

Topography and surface type for each grid location;

Meteorological data: initial state (surface measuring and upper air soundings) and time-dependant boundary conditions.

9.4.2 Fire model

Mid-flame wind speed (given by MEMO)

Type of fuel and fuel moisture.

9.4.3 MARS photochemical model

Topography and surface type for each grid location;

Meteorological data: wind speed and direction, turbulent kinetic energy, Monin-Obukhov length and friction velocity (given by MEMO);

Emission data (VOC, NO_x and CO): forest fire and a diurnal cycle of all emitters (traffic, industry, biogenics).

Initial and boundary conditions

9.5 PHYSICAL OUTPUTS

9.5.1 MEMO meteorological model

Three dimensional fields: wind speed and direction, turbulent kinetic energy, Monin-Obukhov length and friction velocity.

9.5.2 Fire model

Spread rate in the maximum spread direction, fire size and shape.

9.5.3 MARS photochemical model

Three dimensional concentration fields: O_3, NO_x and CO.

9.6 DEVELOPMENT TOOLS AND PLATFORMS

UNIX

9.7 CONTACT

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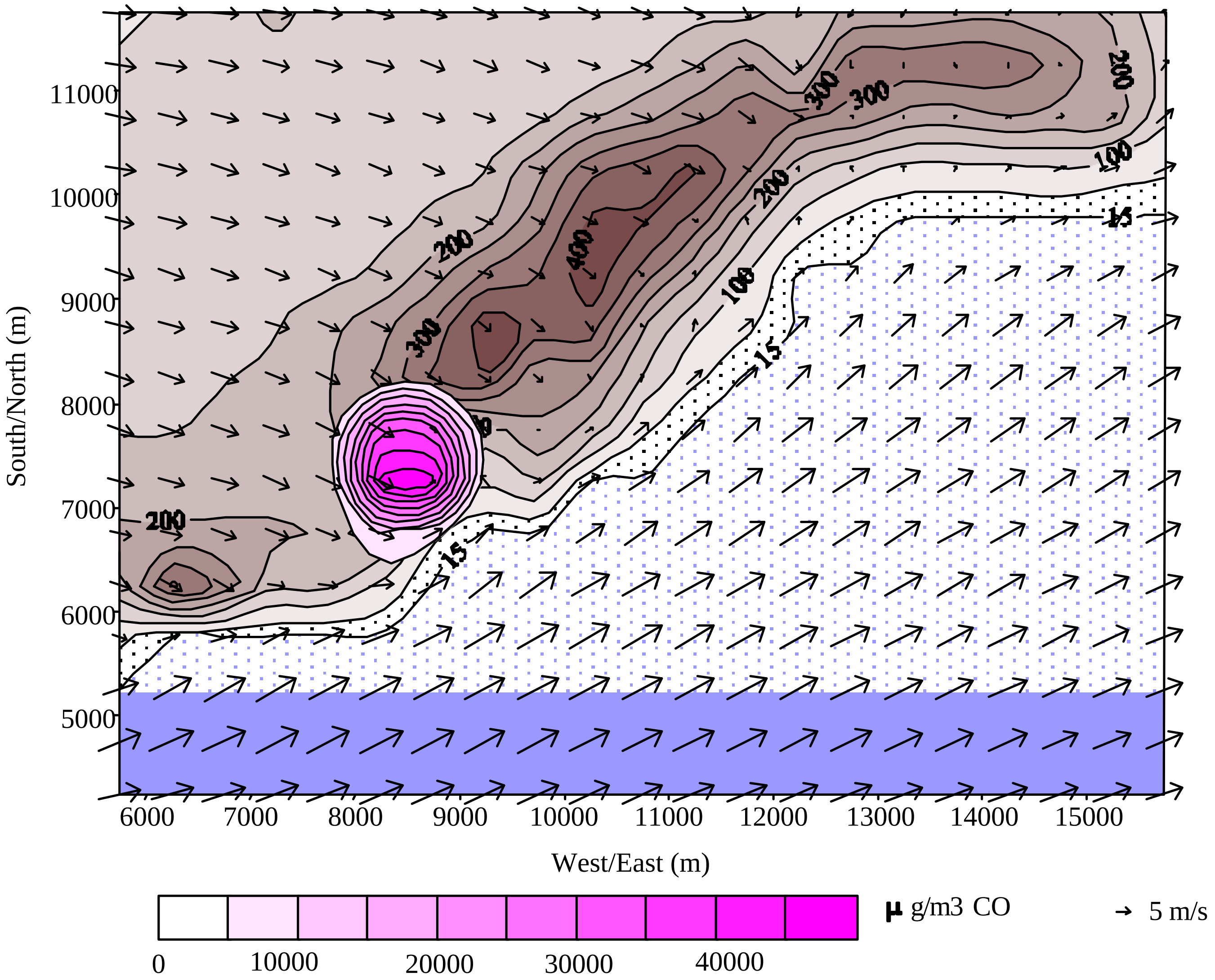

Figure 9-2 : Exemple of simulation
Horizontal ground pattern of wind and CO concentrations

10 DISPERFIRE

10.1 WILDFIRE MODELLING CLASSIFICATION

Smoke dispersion model - Physical Approach

10.2 MAIN PHYSICAL MODELS INCLUDED IN THE CODE

10.2.1 Modified NUATMOS meteorological model

Three dimensional wind field diagnostic model (Ross, 1988) with the calculation of effective viscosity (Miranda, 1998);

10.2.2 Fire progression model

Based on Rothermel model (spread model of low intensity surface forest fires)

10.2.3 SMOKE dispersion model

Three dimensional Lagrangian stochastic model;

10.3 NUMERICAL RESOLUTION METHODS AND PHYSICAL MODELS

10.3.1 NUATMOS meteorological model

Interpolation of meteorological observations throughout the domain satisfying conservation equation for mass, in terrain-following coordinates and variable vertical grid spacing.

10.3.2 Fire progression model

Rothermel model

10.3.3 SMOKE dispersion model

3D Lagrangian approach. Markers whose displacement reproduces the statistics of the considered turbulent transport simulate the dispersion of the pollutant. The dispersion grid is in terrain-following coordinates and variable vertical grid spacing.

Estimation of fire emissions according to Miranda (1998);

Plume rise calculation according to Briggs (1969) formulas.

10.4 PHYSICAL INPUTS

10.4.1 NUATMOS meteorological model

Topography for the simulation domain;
Meteorological data: surface measurements and upper air soundings (if available)

10.4.2 Fire model

Mid-flame wind speed
Type of fuel and fuel moisture.

10.4.3 SMOKE dispersion model

Topography for the simulation domain;
Meteorological data: wind speed and direction and effective viscosity (given by NUATMOS);
Emission data (NO_x and PM10 and PM2.5)

10.5 PHYSICAL OUTPUTS

10.5.1 NUATMOS meteorological model

Three dimensional fields: wind speed and direction and effective viscosity

10.5.2 Fire model

Spread rate in the maximum spread direction.

10.5.3 SMOKE dispersion model

Three dimensional concentration fields: NOx and PM10 and PM2.5.

10.6 DEVELOPMENT TOOLS AND PLATFORMS

FORTRAN 90, Windows

10.7 CONTACT

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10.8 REFERENCES

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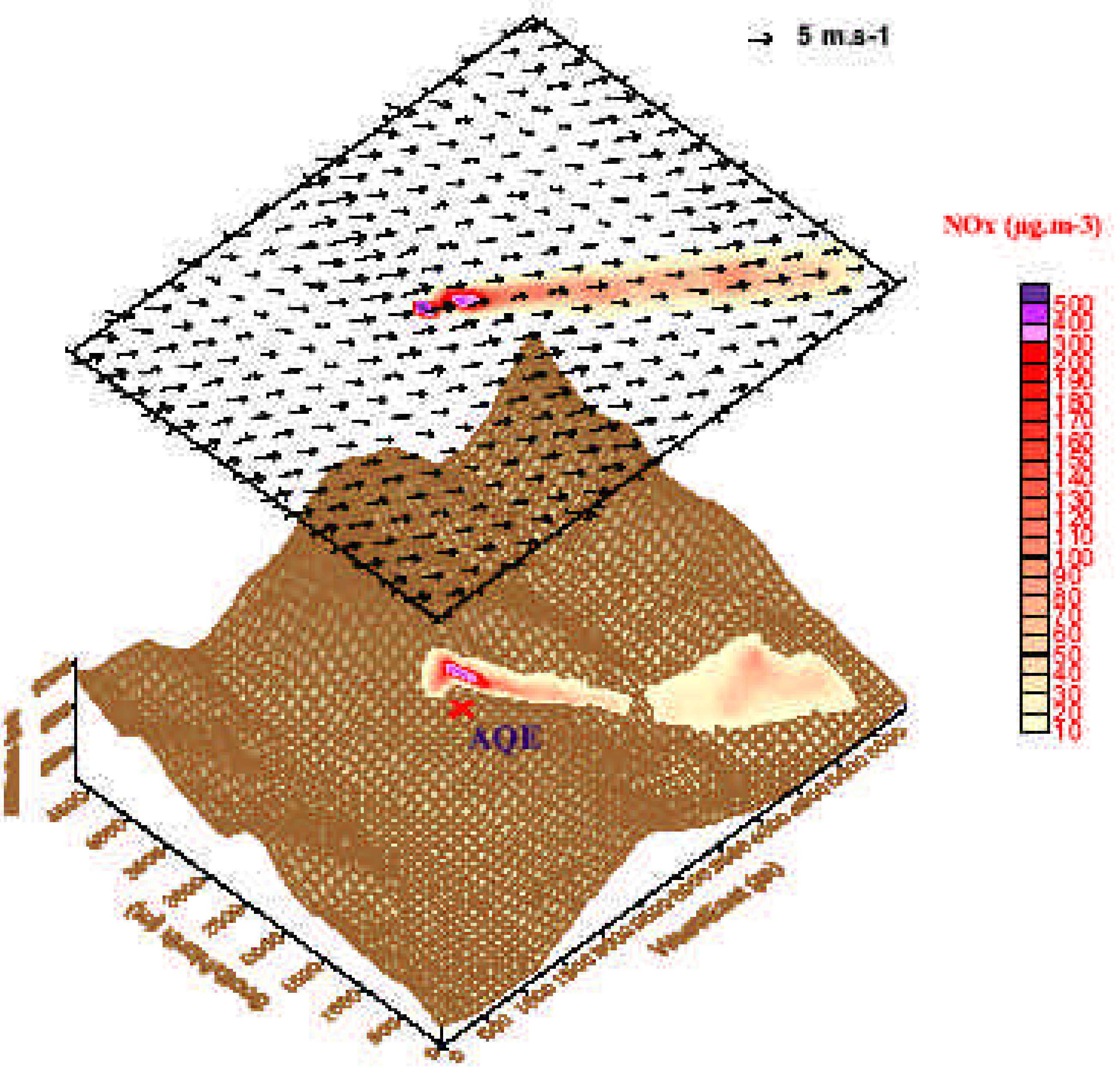

Figure 10-1: Example of simulation :
NOx concentrations and wind fields obtained for the burning of a experimental fire.