



Tiger

2-D F.P. Simulator Model

European Commission Research Directorate General Contract No.018505 IP Project FIRE-PARADOX



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The Tyger

William Blake (1757-1827)



**Tyger Tyger, burning bright,
In the forests of the night:
What immortal hand or eye
Could frame thy fearful symmetry?**

**In what distant deeps or skies.
Burnt the fire of thine eyes?
On what wings dare he aspire?
What the hand, dare seize the fire?**

**And what shoulder, & what art,
Could twist the sinews of thy heart?
And when thy heart began to beat
What dread hand? & what dread feet?**

**What the hammer? what the chain,
In what furnace was thy brain?
What the anvil? what dread grasp
Dare its deadly terrors clasp?**

**When the stars threw down their spears
And watered heaven with their tears:
Did he smile His work to see?
Did he who made the lamb make thee?**

**Tyger Tyger burning bright,
In the forests of the night:
What immortal hand or eye
Dare frame thy fearful symmetry?**



Tiger – 2D Fire propagation model



The concept

Available fire propagation simulators are based on either 2D (rather simplistic empirically-based) or 3D (complicated, physically-based) spatial representations, the latter requiring very heavy computational capacity. Tiger is a new model characterised by an intermediate level of complexity.

This tool is based on a modular modelling approach and on the integration of different sub-models (combustion, convection/diffusion, irradiation, wind, insolation, fire spotting). The philosophy is that complex systems can be described by simple processes, with complexity arising as an emergent property of their integration. Further, we believe in a declarative modelling approach with transparent presentation of the model structure and sub-model interactions.

The software interface uses Google Earth technology for visualisation. The models are designed to simulate fire propagation in various conditions of fuel heterogeneity and include wind/fire interactions.

The model is aimed to be an advanced tool for teaching applications and a powerful demonstrator of the philosophy of the Fire Paradox project, able to show the interactions between wind and fire in different landscape scenarios.

The software technology

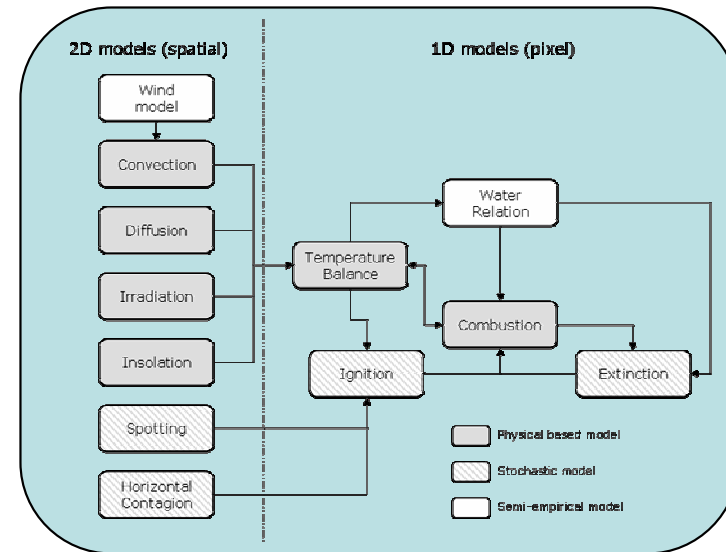
A variety of technologies are used in Tiger:

- WASP Engineering for wind simulation, www.wasp.dk/Products/WEng.html
- MATLAB for convection/diffusion processes (PDE), www.mathworks.com
- Simile for combustion model and other “pixel” processes (ODE), www.simulistics.com
- C++ for insolation submodel
- .net for GUI and model integration

The user interface is a WinForms application developed with Microsoft Visual Studio and using the Google Earth web-browser plug-in.

All models are integrated into a single program by Microsoft Visual Basic .NET

Model design



The team (expertise and roles)

Università di Napoli Federico II

- Stefano Mazzoleni, applied ecology, coordination and integrated model design
- Francesco Giannino, mathematics, integrated model design and combustion model
- Massimiliano d’Aquino, electrical engineering, convection/diffusion model
- Mariano Sirignano, chemical engineering, combustion model
- Andrea d’Anna, chemical engineering, combustion model design

World in a Box Finland OY

- Duncan Heathfield, programmer, wind model integration and software design
- Qiangbing Li, PhD physics, programmer, software integration
- Ray Drummond, programmer, GUI and Google Earth technology
- Niko Rosvall, programmer, software and PDA tools

Instituto Superior de Agronomia

- Francisco Rego, applied ecology, integrated model design

University of Idaho

- Chad Hoffman, fire modelling, comparative simulations



Tiger – GUI

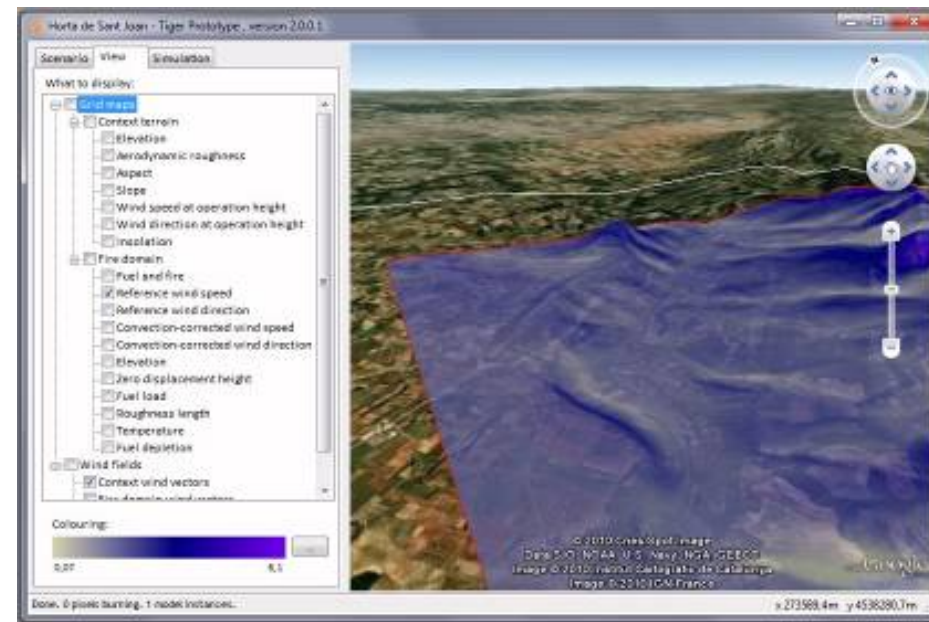
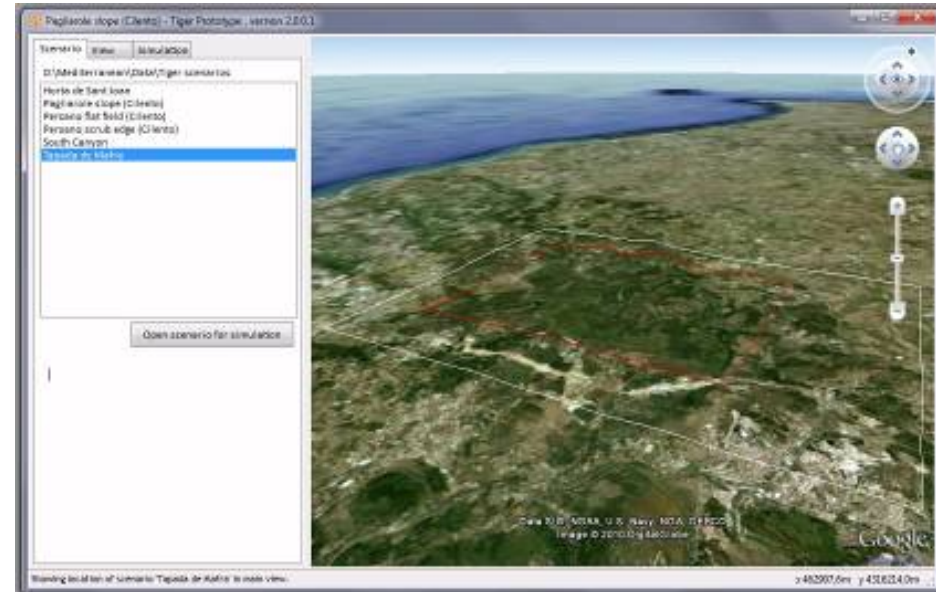
The concept

The program interface is intended to allow users to model any situation ("scenario") for which they have adequate data. The minimum requirement is an elevation grid map describing the fire area and its surroundings, but where the fuel is non-uniform, some kind of vegetation map is needed. These scenario data files must be collected into a folder on the computer with a simple XML configuration file. Each scenario consists of the fire modelling domain: a rectangular area of fuel data in which the fire may spread, and a 'context area' describing the terrain surrounding the fire model domain. This context area is used for wind and insolation calculations. A list of available scenarios is shown when the program starts. The simulation can begin when one scenario is selected and opened.

When a scenario is opened, a list of viewable data is presented. These include grid maps, wind vectors and other features. The data are presented as geo-located overlays on Google Earth views, so it is possible to explore the displayed information in three dimensions. Both input data and simulation results are displayed in this way. The results can be exported to a file for use in other applications, and can be easily opened in a new Google Earth session for combination with other available data as needed.

This version of the program supports various basic fire simulation control operations: ignition points can be set and wind conditions can be edited. The simulation can be run forward for a number of steps, and the display is refreshed automatically as the modelling proceeds.

Screen shots with modelling domain





Tiger – combustion model

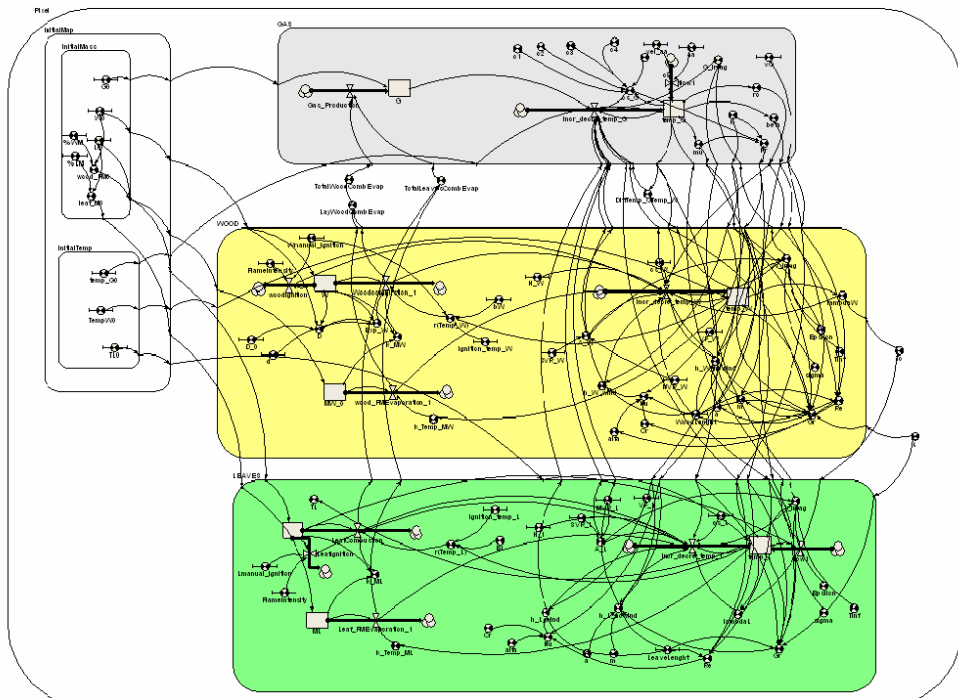
The model

The combustion model handles the fuel consumption and heat production in a cell and it is conceived as different sub-models (see equation box on the right). The within cell temperature balance is provided to the convection/diffusion model for balancing with neighboring cells.

The model is able to represent the mass dynamics due to fire consumption of different fuel types (leaves and wood), the moisture evaporation and the temperature balances for the following state variables:

gas mass (G), gas temperature (T_G), leaf mass (L), leaf moisture (ML), leaf temperature (T_L), leaf moisture temperature (T_{ML}), diametric wood classes (W), wood moisture (MW), wood temperature (T_W), wood moisture temperature (T_{MW}).

Simile model diagramme



Leaf and wood consumption

$$\frac{dL}{dt} = -k_{ML} \cdot r(T_L) \cdot L \quad \frac{dW}{dt} = -k_{MW} \cdot r(T_W) \cdot \min(W, Exp_W)$$

where, k_{ML} , k_{MW} parameters represent the effect of leaf and wood moisture on combustion, $r(T_L)$, $r(T_W)$ leaf and wood reaction rate (Arrhenius factor) and Exp_W is the exposed wood mass

Water relation

$$\frac{dML}{dt} = -k_{TML} \cdot ML \quad \frac{dMW}{dt} = -k_{TMW} \cdot MW$$

where k_{TML} and k_{TMW} are the leaf and wood moisture evaporation parameters

Leaf and Wood temperature balance

$$\frac{dT_i}{dt} \cdot cs_i \cdot i = \sum_{i=L,W} [A_i \cdot (T_G - T_i) \cdot (h_{i_wind} + h_{i_no_wind})] + \frac{di}{dt} \cdot H_i - \sum_{i=L,W} \frac{dMi}{dt} \cdot \lambda_{i_vap} - S_i \cdot \varepsilon_i \cdot \sigma \cdot (T_i^4 - T_\infty^4)$$

where $i=L$ and W , cs_i are the weighted average of specific leaf and wood heats, H_i are the leaf and wood heat content

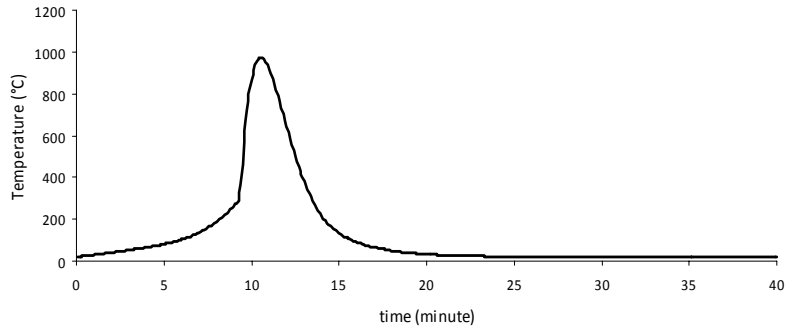
Gas temperature balance

$$\frac{dT_G}{dt} \cdot cs_G \cdot G = \sum_{i=L,W} A_i \cdot (h_{i_wind} + h_{i_no_wind}) \cdot (T_i - T_G) + \sum_{i=L,W} S_i \cdot \varepsilon_i \cdot \sigma \cdot (T_i^4 - T_\infty^4) + \sum_{i=L,W} \frac{dMi}{dt} \cdot \lambda_{i_vap}$$

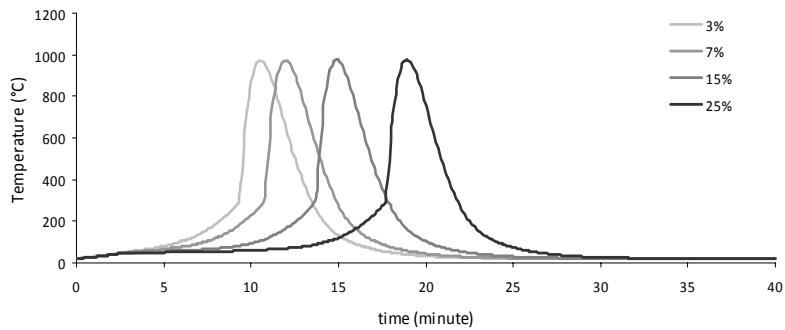
where, cs_G is the gas specific heat, A_i are the heat transfer surface areas, h_{i_wind} are heat transfer coefficients under windy conditions, $h_{i_no_wind}$ are the heat transfer coefficients under non-windy conditions, S_i are the irradiation surfaces, ε_i are the leaf and wood emissivity, σ is the Stephan Boltzman constant, T_∞ is the environmental temperature ($\sim 300K$), λ_{i_vap} are the leaf and wood heat of evaporation



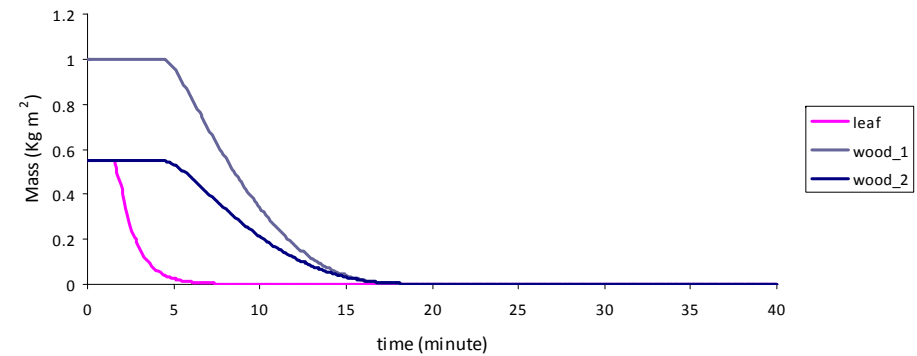
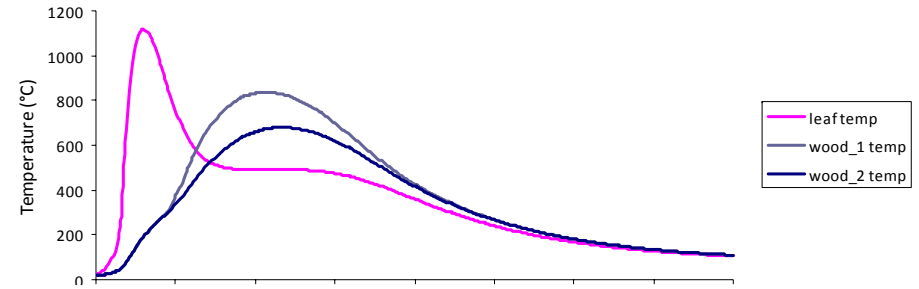
Tiger – combustion simulations



A simulation example of gas temperature around burning leaves (Leaf mass 1 kg m^{-2} , leaf moisture 3%, ignition temperature 270°C).

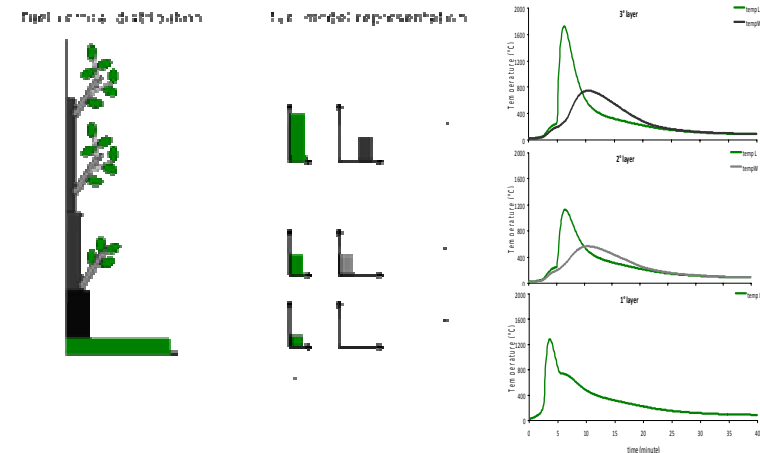


Delayed ignition by increasing moisture levels.



Combustion of leaves and two size classes of wood.

The pixel model can also represent different “vegetation layers” to handle different fire propagation patterns (surface and crown fires – vertical propagation with vertical fuel continuity). Each layer can have its own fuel classes and the combustion can occur independently in each layer and in separate fuel classes. This feature of the pixel model is not yet integrated in the integrated spatial model and it will be used in a future “2.5 D” version

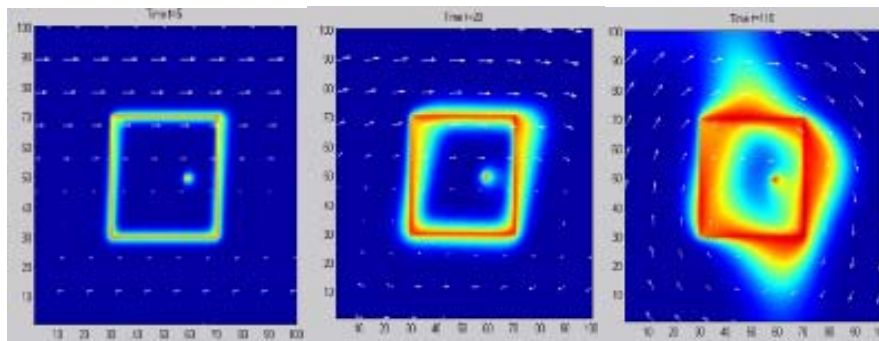
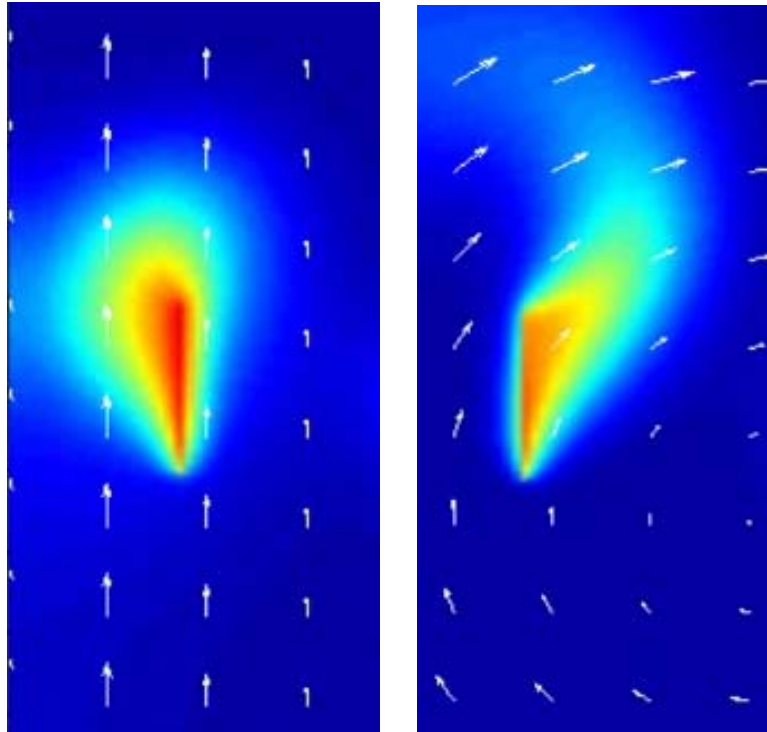




Tiger – convection/diffusion processes

The concept

Wind affecting the fire



Matlab simulations to calibrate the wind influence on convection processes

The model

$$\frac{\partial T}{\partial t} = \underbrace{-\nabla \cdot (v(P,t)T)}_{\text{in plane convective term}} + \underbrace{\nabla \cdot (\chi(P)\nabla T)}_{\text{in plane diffusive term}} - \underbrace{h(T)(T - T_\infty)}_{\text{heat flux due to vertical convection}} + \underbrace{f(t,T)}_{\text{heat source due to combustion}}$$

where the quantities are:

- $T(P,t)$ is the temperature scalar field
- $v(P,t)$ is the wind vector field, function of space and time.

$$\chi(P) = \frac{kV}{m(P)c}$$

k is the air conductivity, V is the volume of the cell, $m(P)$ is the air mass in the cell, c is the specific heat of the air.

$$h(T) = \frac{\bar{h} \cdot V}{m(P)c} (T - T_\infty)^{1/3}$$

is the vertical convection heat transfer coefficient, being the T_∞ ambient temperature

- $f(t,T)$ is the heat source due to combustion in the cell.

The in-plane convective term is responsible for the motion of the air temperature field along the lines of the wind vector field.

$$v(P,t) = v_0(P,t) + \Delta v_1(P,t) + \Delta v_2(P,t)$$

The perturbation of the wind field Δv_1 is computed at each time step by considering the gradient of the vertical convection heat flux. This effect takes into account the creation of a wind field due to temperature gradients. Similarly, the perturbation Δv_2 is proportional to the gradient of the altitude map in the point P and takes into account the effect of slopes on the fire propagation.

The in-plane diffusive term takes into account the mixing between air in the cell and air coming from neighbour cells at different temperatures.

The third term accounts for the heat flux arising from vertical air convection, which produces a temperature decrease due to the heat transfer from the cell to the upper level of air.

The fourth term describes the heat source related to the cell, that is, the combustion which occurs within the single cell. It is a generic function of temperature, time and other parameters and can be interpreted as the pixel model of combustion.



Tiger – wind

The concept

Tiger seeks to avoid the computational load and complexity of a fully 3-dimensional fire-atmosphere model.

The background wind field is calculated from either synoptic (geostrophic) wind inputs, or observations near to the fire area. The WASP Engineering (see box) model is used to calculate local wind speeds and directions, corrected by orography and the surface aerodynamic roughness.

The effects of the fire itself on the wind are emulated by using a convection model to calculate 2-D perturbations and use these to modify the background wind field.

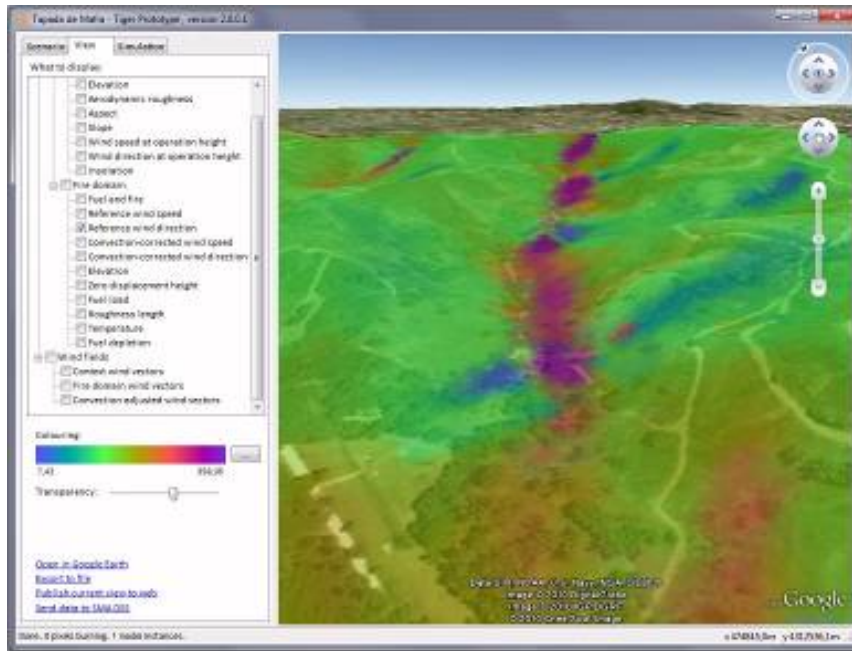
WASP Engineering

The WASP software is produced by the Wind Energy Department (VEA) of the Risø National Laboratory in Denmark, and is the industry standard for wind energy prediction work.

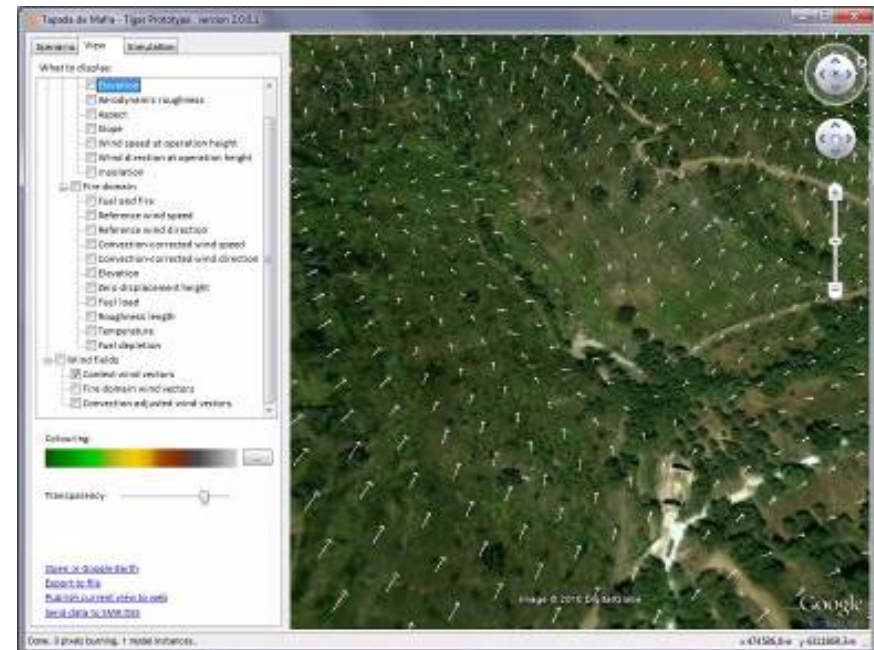
WASP Engineering (WEng) works by taking a wind observed in one place and predicting the simultaneous wind conditions existing in other places in the same landscape.

In WEng, one can set up a modelled situation (domain) with a map describing the orography (elevation) and surface aerodynamic roughness (roughness length). A wind (speed & direction) observed at a given place in the map (x,y,z) or for geostrophic height can be entered, and the program predicts the speed and direction of the wind at any other point in the domain.

The internal flow model is LINCOM, a linear flow model. It calculates the overall flow field in a matter of seconds, and then can derive grids for each height almost immediately.

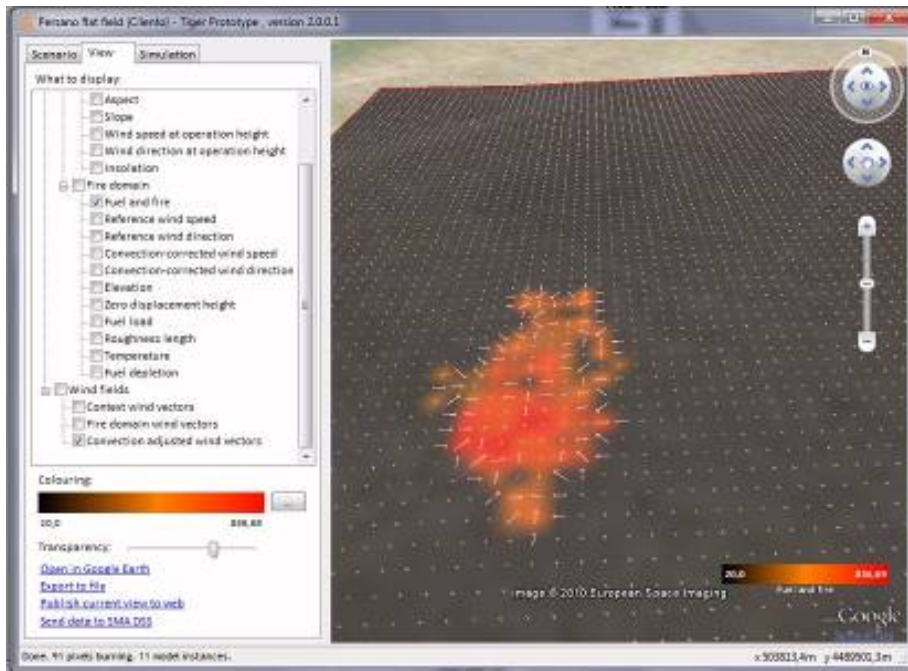


Wind directions and wind vectors modelled in Tiger



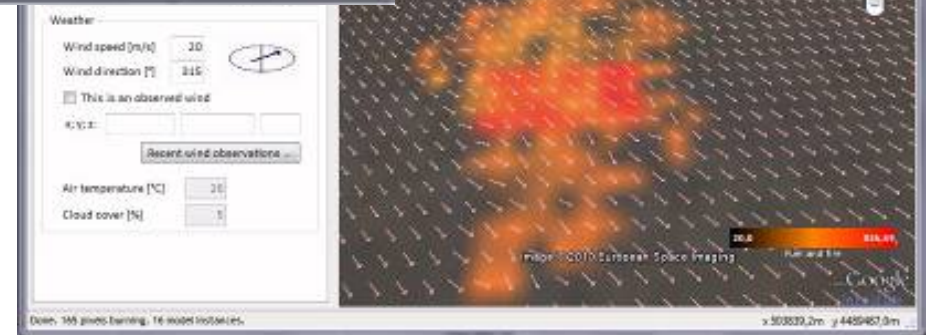
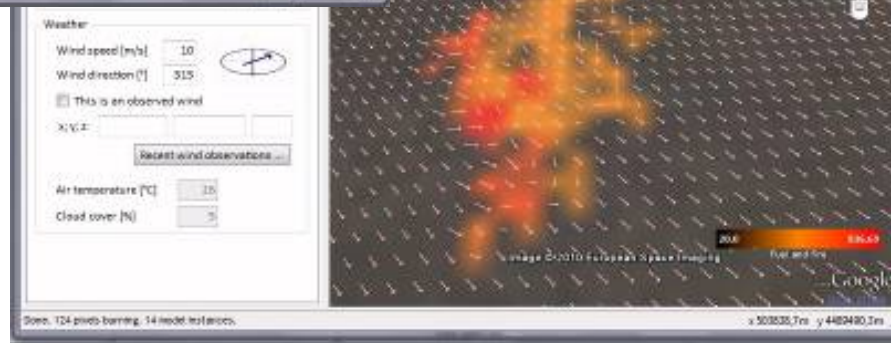


Tiger – fire propagation simulations



The fire wind interactions

Without wind the convection process induce air inflow to the burning area
Increasing wind speed (10 m/s and 20 m/s) reinforces the fire propagation.

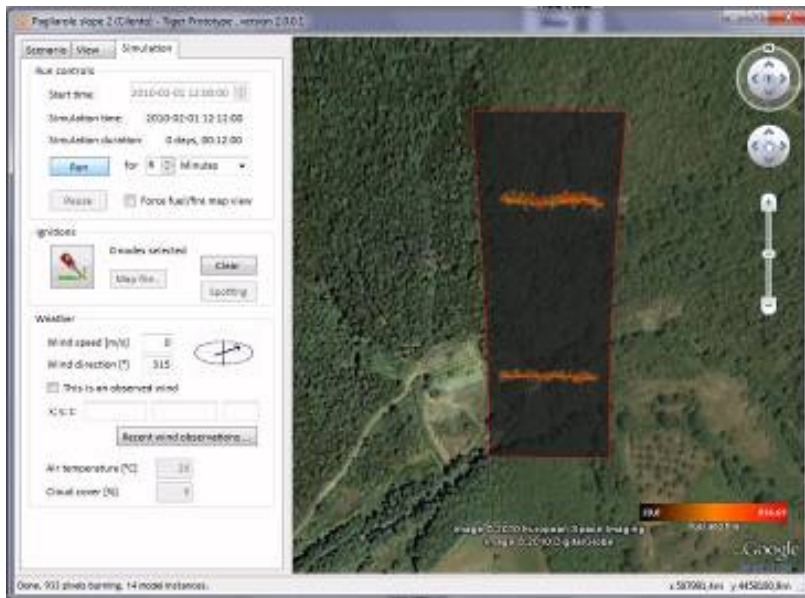
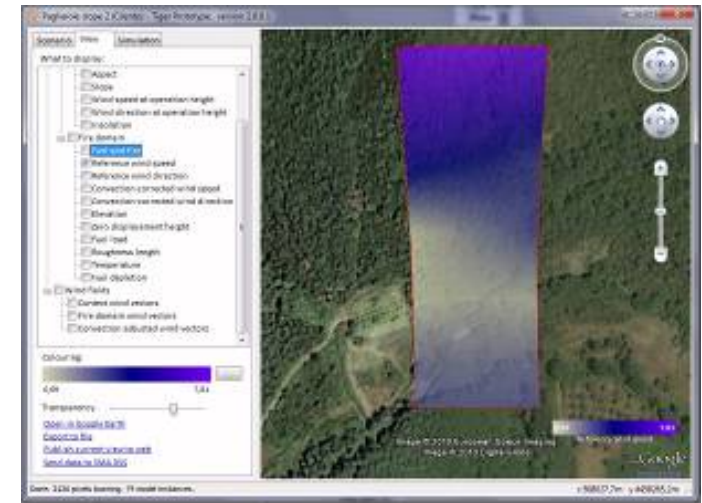
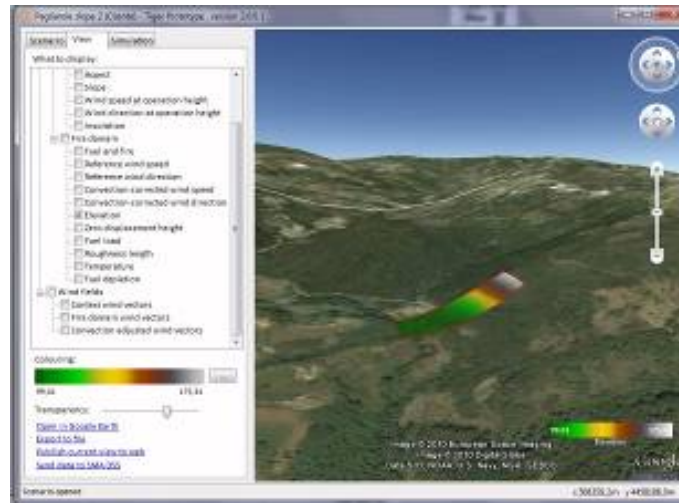




Tiger – fire propagation simulations

Slope effect

Simulations of two fire fronts located in a flat land and a slope show the combined effects of wind intensity and convections processes on fire propagation.



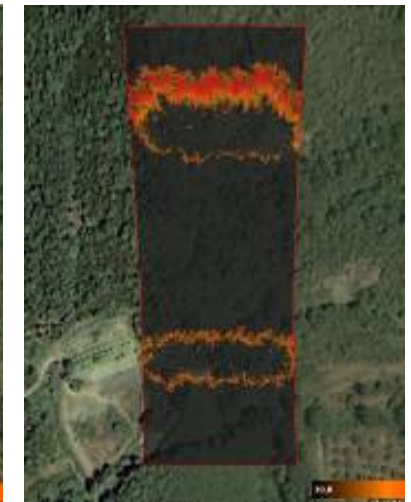
12 minutes



36 minutes



42 minutes



54 minutes



Tiger – Data import and export

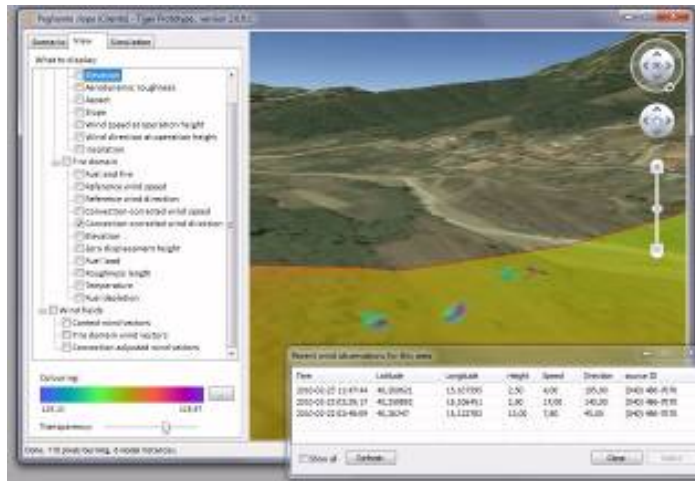
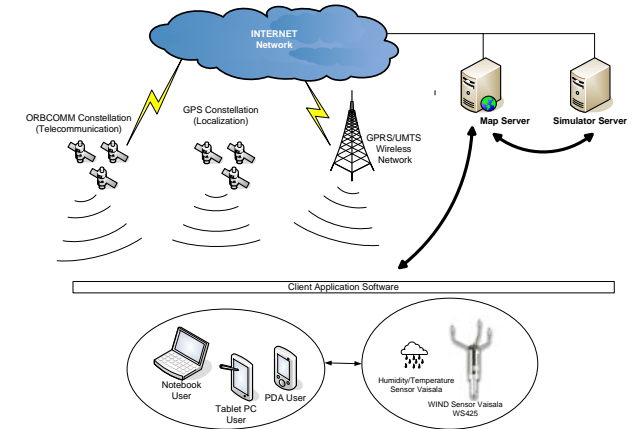
Data exchange

As a proof-of-concept, the program implements several ways in which data can be exchanged with other systems and with people in the field.

We have developed a smartphone application which allows users to contribute automatically geo-referenced wind observations from the area of the fire. These are accumulated on a server, and a list of relevant observations can be viewed from within the Tiger software. A wind observation can be used in the ongoing simulation by simply selecting it from the list.

If the Tiger operator wishes to send a particular data display to other people, it can be published to a web server with a simple mouse click. This image can then be viewed by people in the field, using a PDA or other mobile device.

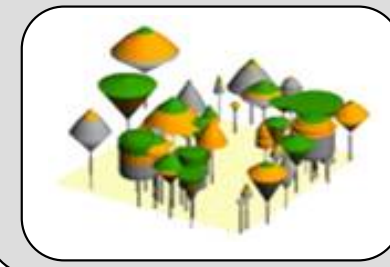
The program also supports the immediate transmission of certain results (e.g. wind field vectors) to another server for representation on other platforms.



Link with the Fuel database and the Fuel manager

The Fuel database is the Fire Paradox repository of physical fuel descriptions, including spatially explicit distributions of fuel particles for plant individuals, layers or scenes.

The Fuel Manager is a software that allows the visual creation of 3D fuel scenes, assisting the positioning of the fuel objects on the terrain. The scenes are stored back into the database, and can be exported for a given grid format to Tiger, using the Fuel database web application.



SMA Wildfire SOS Planner

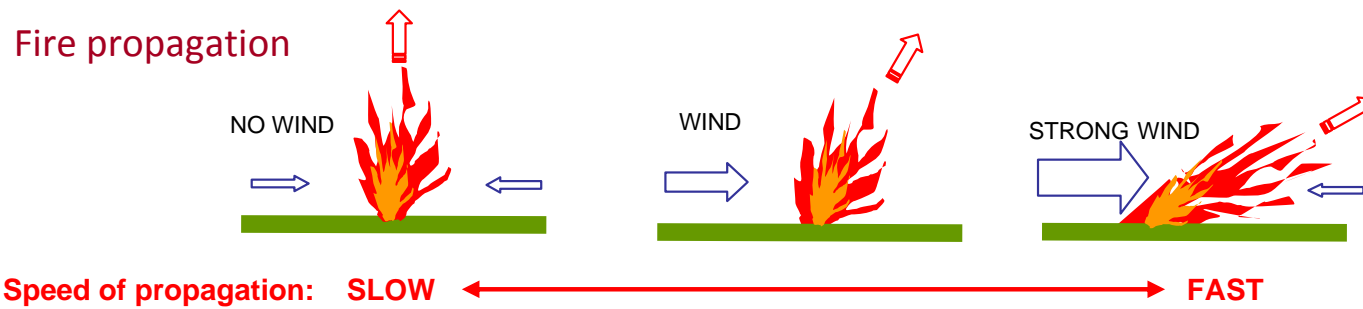
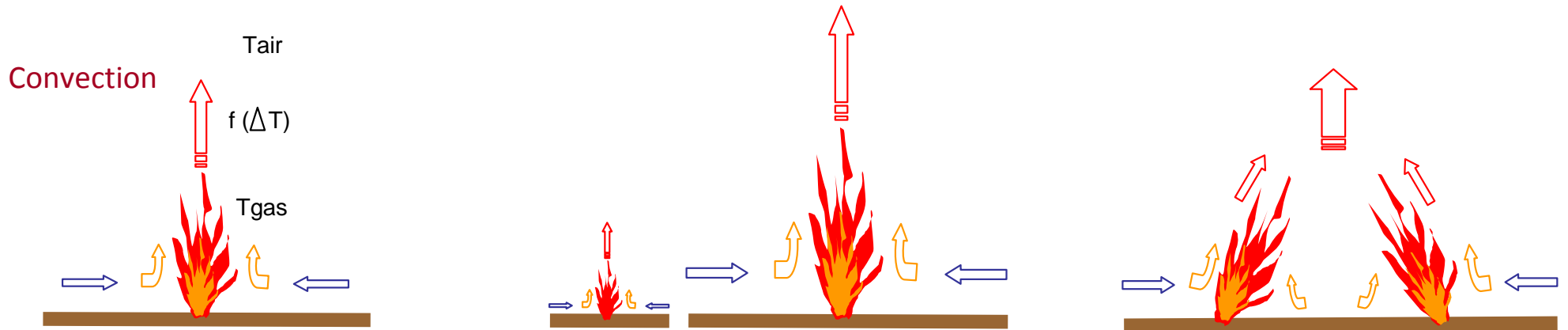
A Decision-Support System (DSS) was designed for the integrated risk management of wildfires in the Campania Region, Southern Italy.

The tool is a complete dynamic IT system collecting and processing information provided by a number of sensing networks. These data are integrated on a web GIS platform to support real-time operational strategies and tactical decisions during a fire event.

The system is able to import data and show maps from Tiger model.



Tiger – conceptual summary



Fire/Wind interactions

Spread of propagation affected by fuel load because of interactions between vertical convection and horizontal wind

