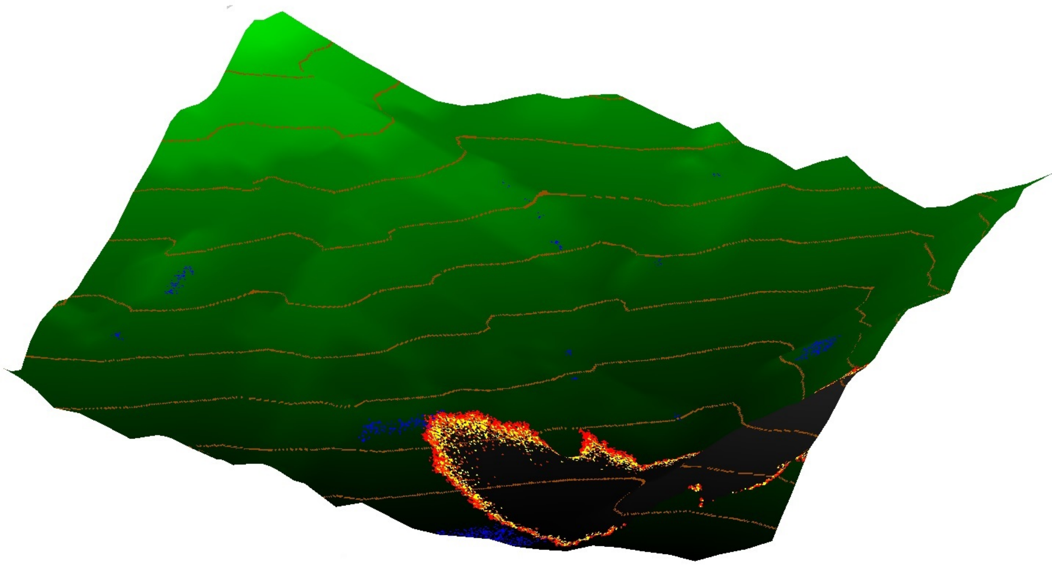
Modelling and Simulating Social Systems with MATLAB



Fire propagation in a forest

Authors:

Daniele Speziali, Francesco Stoppa, Anastasia Gavrilova &

Mattia Bacchetta-Cattori

ETH HS 2013

Contents

1 Abstract

Wildfire may cause significant damage to forest and ecosystems. A mathematical model of the fire propagation can be used to identify the potential of such a catastrophe. With a model you can predict where the fire will probably expand.

We want to model a real section of a forest. We will represent the forest in 3D respecting the conformity of the ground. We also implement a wind direction with an intensity. These two factors will influence the propagation of the fire in the forest. In our model we'll also represent some houses, which are in our forest and which can be damaged from the fire.

2 Individual contributions

With our project we want to simulate the fire propagation on a real forest, where many fires took place. We concentrate on wind direction and intensity and terrain conformation in relationship with the fire propagation. We also implemented every houses, which are on the forest. In the simulation we can see when they burn. In a graph is also possible to see in which step every house burns. It is also possible to choose where the fire starts with an input of the user.

We started together thinking about what to do with our project. We decided together which parameters we wanted to use in the simulation. Francesco founded the terrain in Gordevio and proceeded on the modelling of the forest in MATLAB and helped Daniele on the code. Daniele wrote the matlab code. He studied the influence of the wind and of the slope. He wrote many programs and he adapted them many times according to what we wanted to do with our simulation. Mattia wrote the report and and Anastasia prepared the presentation. They also asked some data about fire propagation in the same region and confronted the real data with the simulation (the real data was unfortunately limited) and analysed the results.

3 Introduction and Motivations

With these model we want to expose the fire propagation as realistic as possible, to see how a fire can expend in a real forest in relationship with the terrain and the wind.

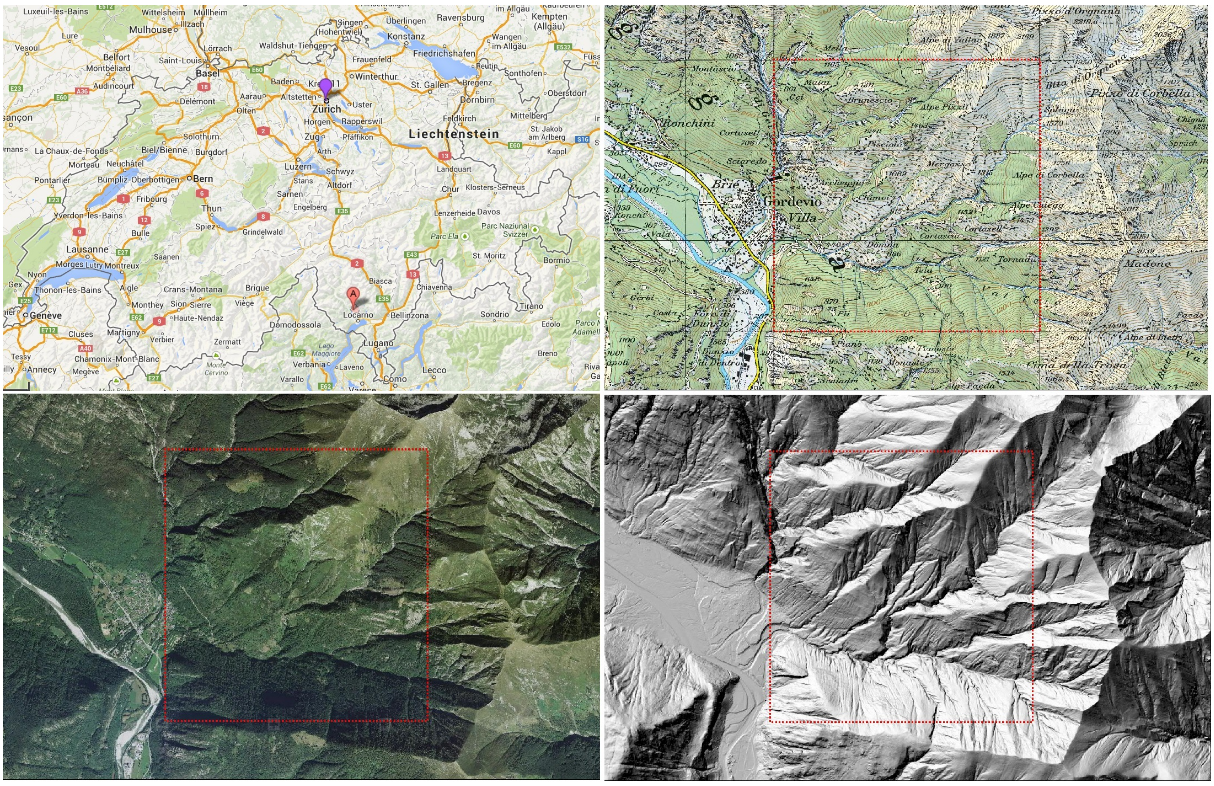
The fire propagation will be tested on a real forest with realistic ground conformation and with real small houses and towns. We want to see where the fire will damage first and which houses will be burned before. If you can predict the fire propagation it could be easier to reduce the impact of a fire.

We expect that a big part of the forest will be burnt, because there are no interferences to the fire propagation in our model. Maybe one small part needs much more time to burn because of the wind direction and the conformation of the forest. We also expect that there will be a part of the forest that is already burned and one part which is burning and this part expands the fire propagation. The part of the forest which is burning will be always bigger and the number of trees which have a contact with a burning tree will increase.

We think that in the fire representation we'll see the relationship with wind intensity and direction and with conformity of the ground.

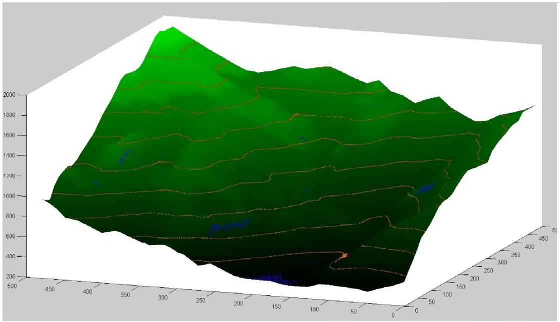
4 Description of the Model

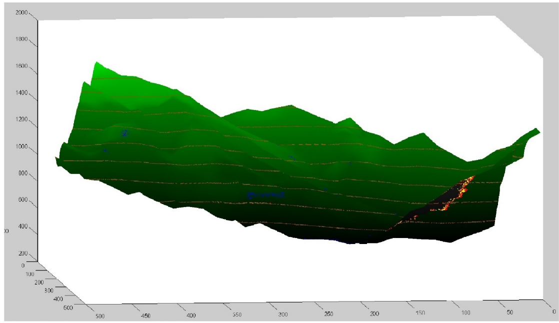
We decided to implement a real forest. The MATLAB model will then represent a fire propagation of this forest. We choose a forest in Ticino (Switzerland) in Gordevio. We choose this place because is a region with high possibility of fire propagation. In *http : //www4.ti.ch/dt/da/sf/temi/incendi−boschivi/incendi−boschivi/catasto−cantonale/* we have found many information about fire propagation in Ticino in the last years.

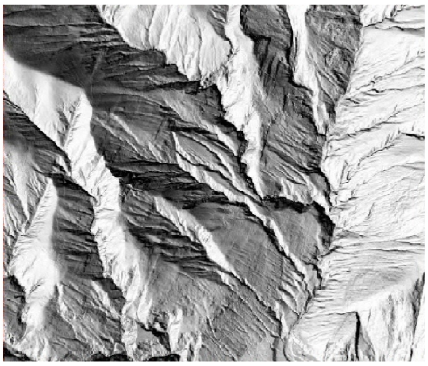


In the figure you can see where Gordevio is and 3 maps (geographic, satellite and topographic) of our forest.

We implemented the forest in our MATLAB model. To do that we saved in a matrix the height of the forest in every point (we partitioned our forest in zones, where every zone has a specific height).







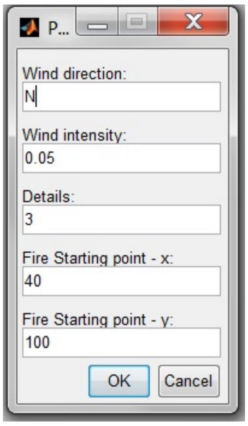
Here you can see the forest that we implemented in MATLAB and the real forest. The real conformity is respected. The difference of green is not as big as in the real map but the altitude of every zone is exactly the same. In brown you can see the level curves.

5 Implementation

Here we want to present our MATLAB model. We don't want to explain our program in details, but only the idea of modelling. We divided the program in several parts: declarations, create the forest, create the terrain model and the simulation.

At the beginning of the program we write the parameters that we will use in the entire model. They are: wind direction: which can assume 8 directions (N, NE, E, SE, S, SO, O, NO), wind intensity, propagation: which tell us how "well" the fire propagates, duration: which tells us how much time a tree needs to be burnt (when they start burning), correction factors and number of steps of propagation.

The user can choose at the beginning of the program some parameters by inputting them: wind direction, wind intensity,how the map is detailed and the fire starting point. In the program we can also choose between some outputs (figure of forest burning, some graphs about the fire propagation, about houses burned, and the figure seen from high).



Then we want to create our forest. We import our matrices. They save information about the ground conformity (hight of every zone and density of three in every zone). Depending on the details the user chooses if the forest will have more or less points. We also import the houses with their position in the forest.

We choose the numbers of trees of the forest, which will be $N * N$. The array map represents the status of every three. From 0 (the tree doesn't burn) to 7 (the three has burnt down). In the simulation the tree will have colors from green (1) to black (7). When a three is burning (1-6) you will see a yellow,orange, red color. The array color saves for each cell 3 values. They represent the RGB color of the cells.

We put the point where fire starts (chosen by the user) and we set all the trees near this (in a $4x4$ box) burning at level 1. We could also save more then one fire and have more then one point which starts burning! In this case we would save the values 1 in *map* in another point of the forest. In our model we chose that the fire will start only in one point.

Now we want to start understand how the ground conformation has a relationship with fire propagation. We know that the fire goes uphills and for this reason if the fire is in a slope it is more possible that the fire will go up then down. For every cell we save some values about the position of the neighbors. We calculate the difference of height for every neighbor and we save the bigger values. The fire will probably have more probability to go there.

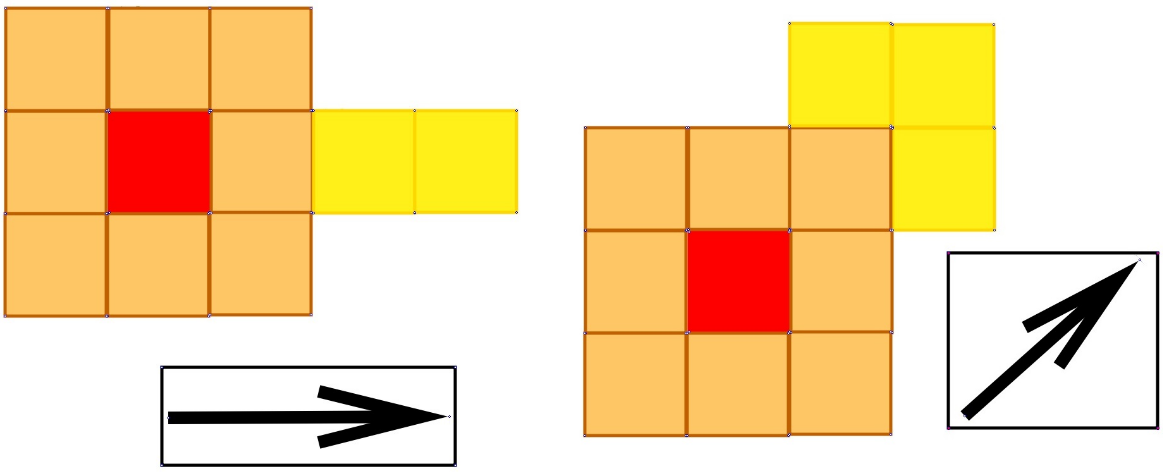
We put the color of the forest. With no fire the forest is green, but we introduced some variation of green due to the height of the cells. When the cell has a big height the color will be light green, in the other case dark. We then have some gradation of green, which should give the possibility to understand better the conformity of the terrain.

In the last part of the program, which is the most important, we implement the simulation. There we will see how the forest will burn in relationship to the wind and the surface.

In this part every single burning cell will influence other cells. But which cells? We explain now how the other cells are influenced by the burning cell. In every case for every influenced cell we set a random number. If this number is smaller then a propagation value then the cell will start burning. This idea will be applied for every cell and in every moment of our model. Now we have to give a value to the propagation (which will be confronted with a random number) and choose which cells are influenced by a burning cell.

- Every burning cell will influence its 8 neighbors. Because of the heat the trees which are near to a burning tree will have a big probability to start burning. This probability also depends on the step of burning of the three. When a tree starts burning the heat around them is not so big, but in the maximal burning step it will be bigger. In our model we implemented these differences of fire propagation probabilities.

- The wind has an influence on the neighbors. How the wind influences the neighbors depends on the wind direction. You can see that in the next figure:



we have two possibilities: straight or diagonal wind. The wind will influence then 2 or 3 more cells. The probability of propagation in these cells depend on the wind intensity.

- The conformity of the forest has an influence on the propagation. If a cell is burning then it is more probably that the fire goes up and that the propagation will go to the cells which have a bigger height. We also have two possibilities: diagonal or straight slope. The propagation value will then change depending on the biggest height difference of a cell. We also have the same possibilities as in the wind propagation. We have the same situation as in the wind figure. We use a similar model to change the propagation value.

Until now in the simulation part we looked at the trees which weren't burning and we implemented a model which induces these trees to start burning. Now we want that in every step we also look at the trees which are already burning. We saw at the beginning of the program that every tree can assume values from 0 to 7 (0 not burning, $1-6$ burning, 7 burned). We want now insert in our model the evolution from 1 to 7.

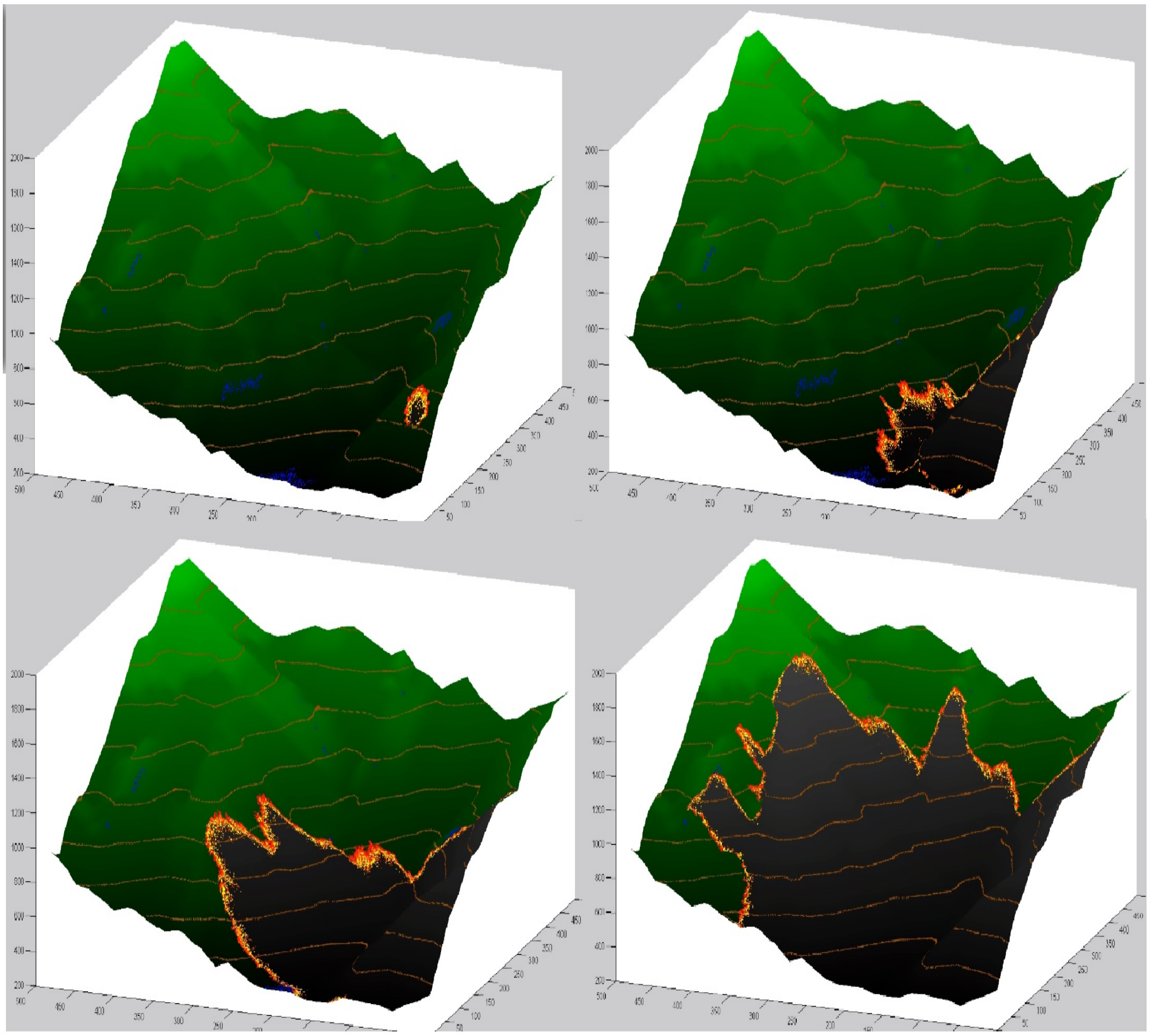
When a tree is burning then if a random number is smaller than $Duration$, it will go to the new step. If a tree reached step 7 it means that it finished its burning cycle and has completely burnt (7).

Now we want that every situation of every tree has a color. We saw that every three has a burning level from 0 to 7. For the representation we now give a color for these cases.

Now we only have to have a figure of our forest with all the colors which represent the situation of every tree. After every step the new situation of the forest will be changed and we will see the new figure until the simulation finishes. We tried to optimize the program. For that we made a program which doesn't recalculate every cell, but a program which updates only the cells which are in the burning area. For the output you can also see the variation of burning trees, burnt trees and not touched trees in a graph.

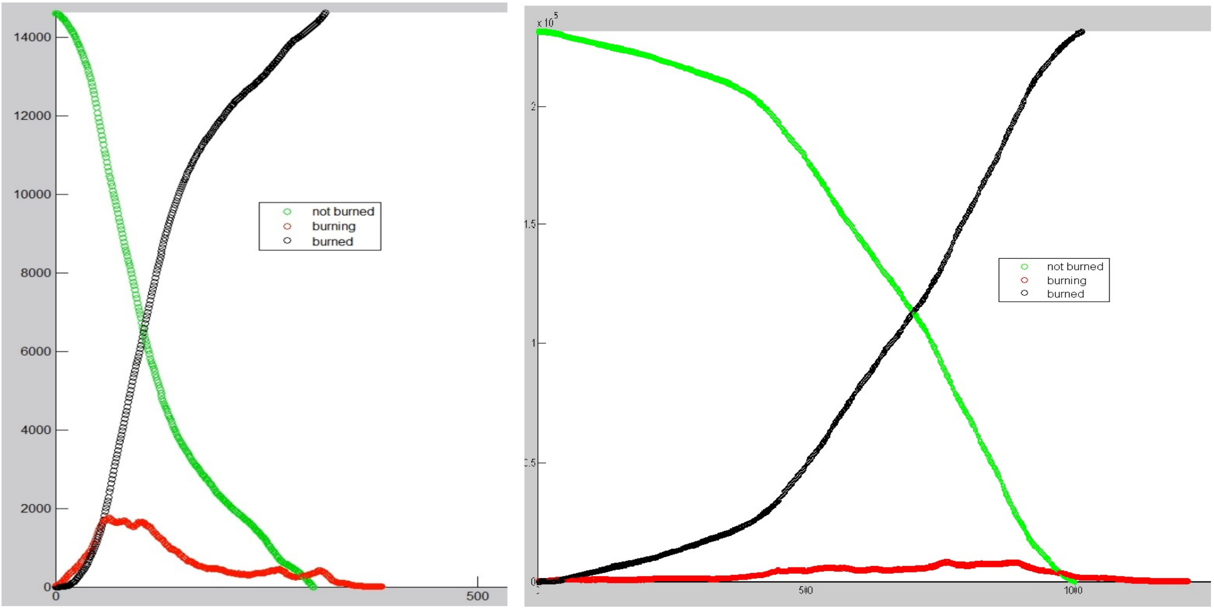
6 Simulation Results and Discussion

Now we expose the output of our program with images. As we said we have 3 outputs: the image of the forest which burns, the graphs about burnt, burning and not burnt trees and the histogram about houses burnt in every step. We start with the animation (start fire: (60,30)):

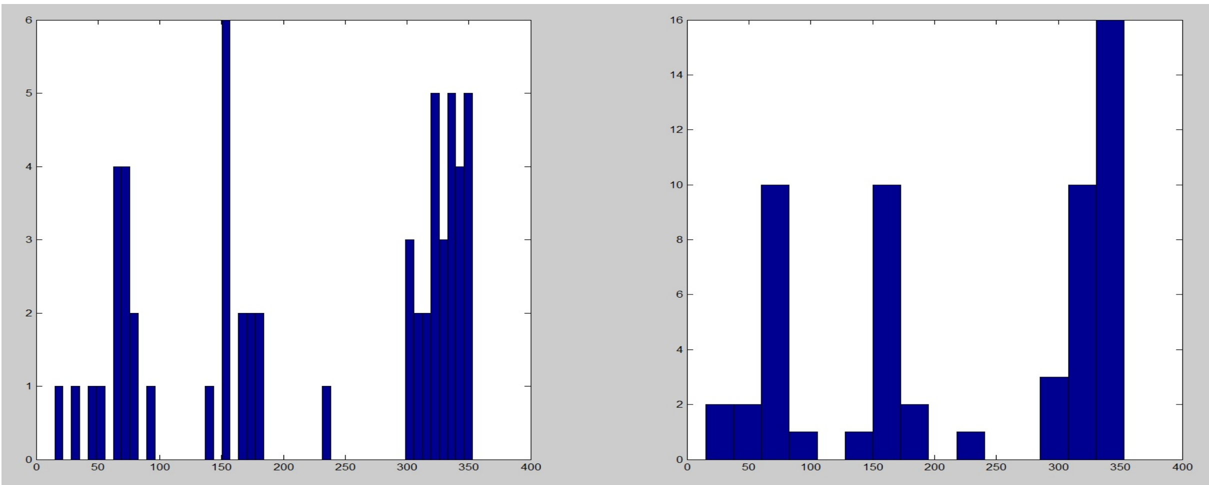


In the animation you can see the fire propagation. We see that propagation has a strict relationship with the ground conformation: the velocity of the propagation in bigger when the fire goes up. We also see the relationship with the wind. If the wind has a direction, then the fire will also have this direction of propagation. If the intensity is bigger then the wind plays a more important part in the simulation and the velocity of propagation is bigger.

We now show the other output of the program: a graph with three burning, burned and not burned for every step. This graph is updated after every step. We now show the results for *Details* 2 and 4.

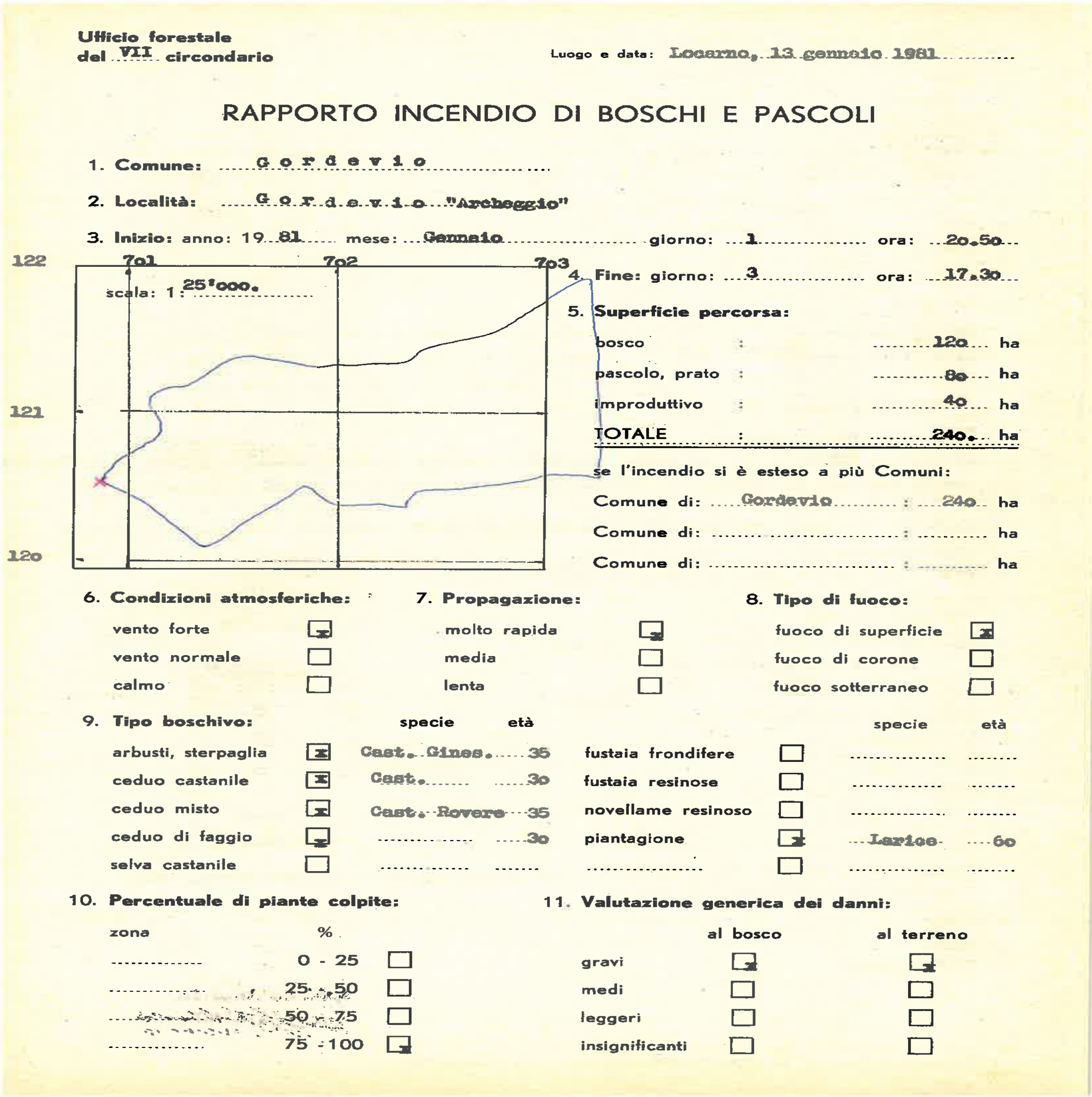


In our model we also have small towns and houses, which can also burn. We represent in an histogram how many houses burn in every step.



7 Summary and Outlook

To compare our model with real fire propagations on the same location, we asked to the fire information center of Ticino the report of the fire in the region near Gordevio. With this information we saw that our model was very similar to the real fire propagation in this reagion. In the first figure below you can see the offcial report of the fire in 1981 and in the second the areas touched by the fire in different fires on the region.



Ufficio forestale
del VII circondario

Luogo e data: Locarno, 13 gennaio 1981

RAPPORTO INCENDIO DI BOSCHI E PASCOLI

1. Comune: G o r d e v i o

2. Località: G o r d e v i o "Archeggio"

3. Inizio: anno: 19 81 mese: Gennaio giorno: 1 ora: 20.50

4. Fine: giorno: 3 ora: 17.3o

5. Superficie percorsa:

bosco	:	12o	ha
pascolo, prato	:	8o	ha
improduttivo	:	4o	ha
TOTALE	:	24o.	ha

se l'incendio si è esteso a più Comuni:

Comune di: Gordevio	: 24o	ha
Comune di:	:	ha
Comune di:	:	ha

6. Condizioni atmosferiche:
- vento forte ☒
- vento normale ☐
- calmo ☐

7. Propagazione:
- molto rapida ☒
- media ☐
- lenta ☐

8. Tipo di fuoco:
- fuoco di superficie ☒
- fuoco di corone ☐
- fuoco sotterraneo ☐

9. Tipo boschivo:

		specie	età			specie	età
arbusti, sterpaglia	☒	Cast. Gines.	35	fustaia frondifere	☐		
ceduo castanile	☒	Cast.	3o	fustaia resinose	☐		
ceduo misto	☒	Cast. Rovere	35	novellame resinoso	☐		
ceduo di faggio	☒		3o	piantagione	☒	Larice	6o
selva castanile	☐				☐		

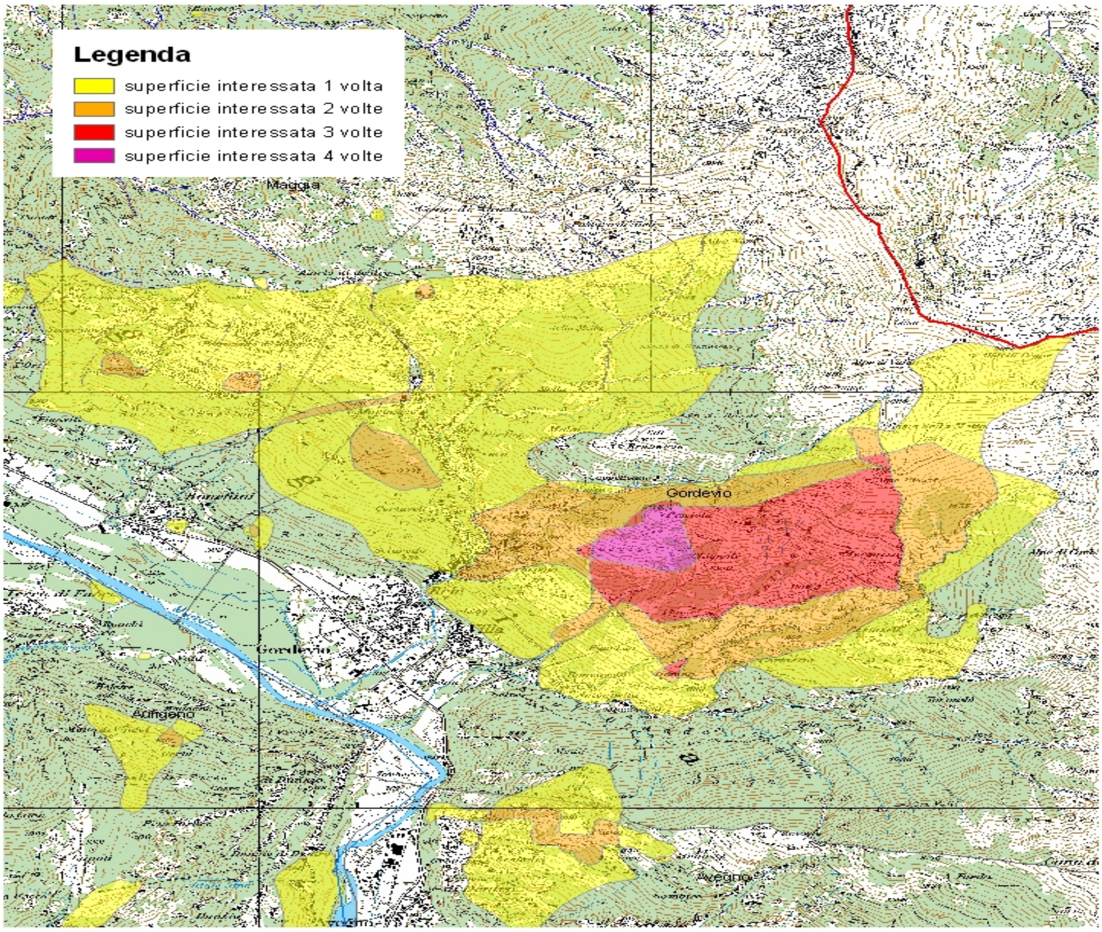
10. Percentuale di piante colpite:

zona	%	
	0 - 25	☐
	25 - 50	☐
	50 - 75	☐
	75 - 100	☒

11. Valutazione generica dei danni:

	al bosco	al terreno
gravi	☒	☒
medi	☐	☐
leggeri	☐	☐
insignificanti	☐	☐

Intensità degli incendi nel 7° Circondario
periodo 1947 - 2004



In this program you can input the wind direction, its intensity and the point where fire starts. Because of the input you can use this program for many fire propagations in this forest, you only have to input some data. A fire propagation has absolutely much more variables like humidity and water in the terrain. Our program looks only at wind and at the conformation of the the forest. It also includes all the houses in the forest, where people may be in danger. With this model we can try to prevent the fire propagation and understand where for example fireman should start working or where people should be evacuated and houses protected. This is the real application of our work. This is not only a casual fire propagation on a casual forest, but is a model which works on a real forest with real houses or farmhouses. We also implemented a method where wind and ground conformation influence the fire propagation.

References

[1] Simo Hostikka and Johan Mangs, *MASIFIRE Map based simulation of fire in forest-urban interface*, VTT Building and transport.

[2] Rapporto 1981 Incendio Gordevio, Catasto Cantonale Incendi boschivi Cantone Ticino.

[3] Alexander Stepanov, James MacGregor Smith, *Modeling wildfire propagation with Delaunay triangulation and shortest path algorithms*, European Journal of Operational Research.

[4] Richard C.Rothermel, *A Mathematical model for predicting fire spread in wildland fuels*, Intermountain forest and range experiment station, Utah.

[5] C. Tymstra, R.W. Bryce, B.M. Wotton, S.W. Taylor, and O.B. Armitage, *Devolopment and Structure of Prometheus the Canadian Wildland Fire Growth Simulation Model*, Northern Forestry Centre.

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Declaration of Originality

This sheet must be signed and enclosed with every piece of written work submitted at ETH.

I hereby declare that the written work I have submitted entitled

Fire propagation in a Forest

is original work which I alone have authored and which is written in my own words.*

Author(s)

Last name	First name
Bacchetta-Calton, Gavrilova, Speziali, Stroppa	Mattia, Anastasia, Daniele, Francesco

Supervising lecturer

Last name	First name
Kuhn	Tobias

With the signature I declare that I have been informed regarding normal academic citation rules and that I have read and understood the information on 'Citation etiquette' (http://www.ethz.ch/students/exams/plagiarism_s_en.pdf). The citation conventions usual to the discipline in question here have been respected.

The above written work may be tested electronically for plagiarism.

Zürich, 13.12.13
Place and date

Signature

*Co-authored work: The signatures of all authors are required. Each signature attests to the originality of the entire piece of written work in its final form.

Print form

Agreement for free-download

We hereby agree to make our source code of this project freely available for download from the web pages of the SOMS chair. Furthermore, we assure that all source code is written by ourselves and is not violating any copyright restrictions.

Mattia Bacchetta-Cattori, Anastasia Gavrilova, Francesco Stoppa and Daniele Speziali