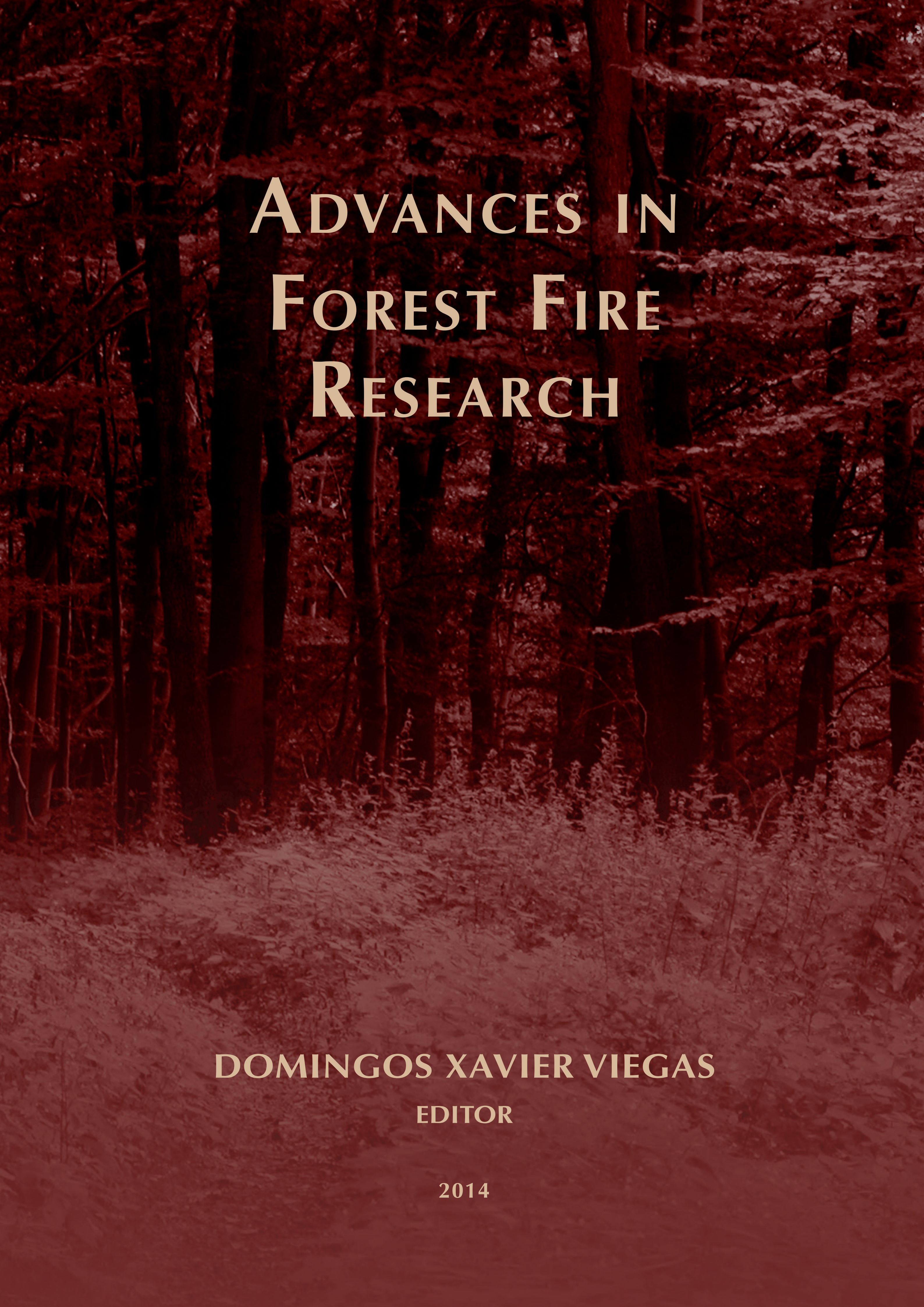

# Advances in Forest Fire Research

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# Map partitioning to accelerate wind field calculation for forest fire propagation prediction

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**Abstract**
Forest fire is significantly affected by wind. However, meteorological wind is modified by terrain topography in such a way that a different value of wind speed and direction is given on every point. To estimate forest fire propagation on such conditions it is necessary to couple a wind field model to the forest fire propagation model. These models are time consuming from the computational point of view and may be parallelised to make them feasible in an operational scenario. So, a map partitioning has been applied to accelerate wind field calculation. The results show that the wind field and the forest fire propagation prediction are not significantly affected by map partitioning and the time to reach the forest fire prediction is significantly reduced.

***Keywords**: Wind field, map partitioning, data parallelism, forest fire propagation prediction*

## 1. Introduction

Forest fire propagation prediction is a difficult task due to the amount of variables that take part in the process, the complexity to develop a computational model that faithfully describe the real phenomenon and the lack of accuracy in certain environmental measurements or terrain features. Therefore, despite there exists several fire spread simulators [1][2][3], the results are still far from real behaviour. To overcome such difficulty a Two-Stage prediction strategy [4][5] was developed to improve the quality of input parameters. In the first stage a Genetic Algorithm (GA) is used to determine the values of the parameters that best reproduce the fire propagation during an observation interval. GAs work in an iterative way where at each iteration a set of individuals (representing fire scenarios) are executed, the provided results are compared to the actual fire propagation to rank them and the genetic operators are applied to determine the next generation. At the end of the iterative process, the best individual is used in the second stage to predict the fire propagation in the next time interval. In this work FARSITE [2] is used as forest fire propagation simulator.
However, certain parameters, such as wind, present a spatial distribution or variation along the terrain due to topographic effects. The wind provided by a global weather forecast model or measured at a meteorological station in some particular point is modified by the topography of the terrain and has a different value at each point of the terrain. Therefore, a single value does not represent the wind in each point of the terrain. To estimate the wind speed and direction at each point of the terrain it is necessary to apply a wind field model that determines those values at each point depending on the terrain topography [6].
When coupling wind field and forest fire propagation models, each individual consists of executing two computing demanding simulations in a pipeline way. First, a wind field model must be executed to provide a high resolution wind field adapted to the underlying topography. The output provided by this wind field model will be fitted into a forest fire spread simulator to generate the fire front evolution Figure 1).

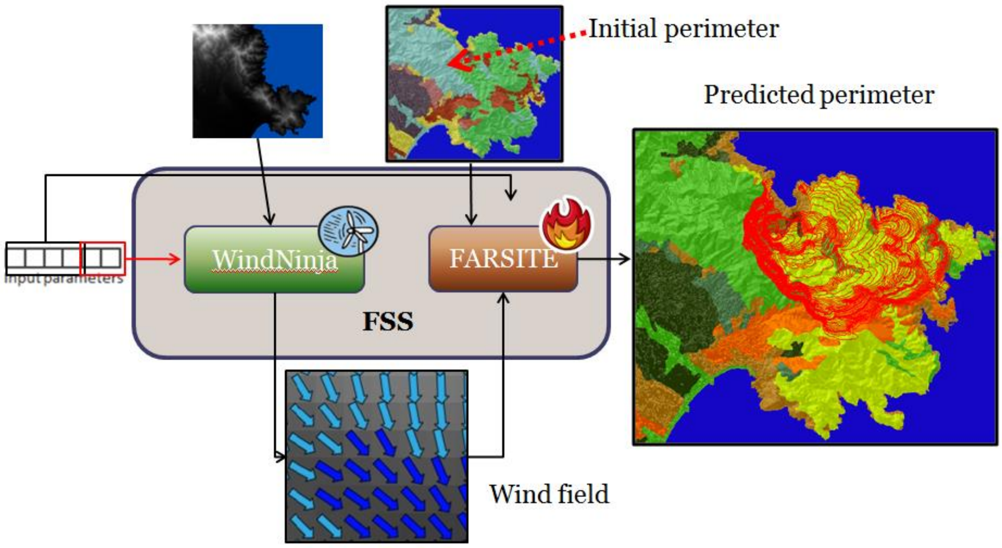


*Figure 1 –Coupling Model*

## 2. WindNinja and map partitioning

WindNinja [7] is a wind field simulator that calculates the effect of topography on wind flow and provides the wind speed and direction at each point of the terrain given a meteorological wind value (Figure 2). The main problem is that, when the map has a considerable size (30x30 Km) and the resolution is high (30x30m), it requires an unaffordable execution time and a huge amount of memory that may not be available on a single computational node. Such limitations make impractical the effective prediction of fire spread with accurate wind field. Moreover, the amount of memory required to solve the wind field increases linearly with the number of cells of the map making unaffordable to be solved a map with a large number of cells in a single node. It means that calculating the wind field of a 1500x1500 cells map on a single node with 4GB of main memory fails and no output is delivered. Therefore, it is necessary to apply some parallelization technique to reduce execution time and memory requirements.

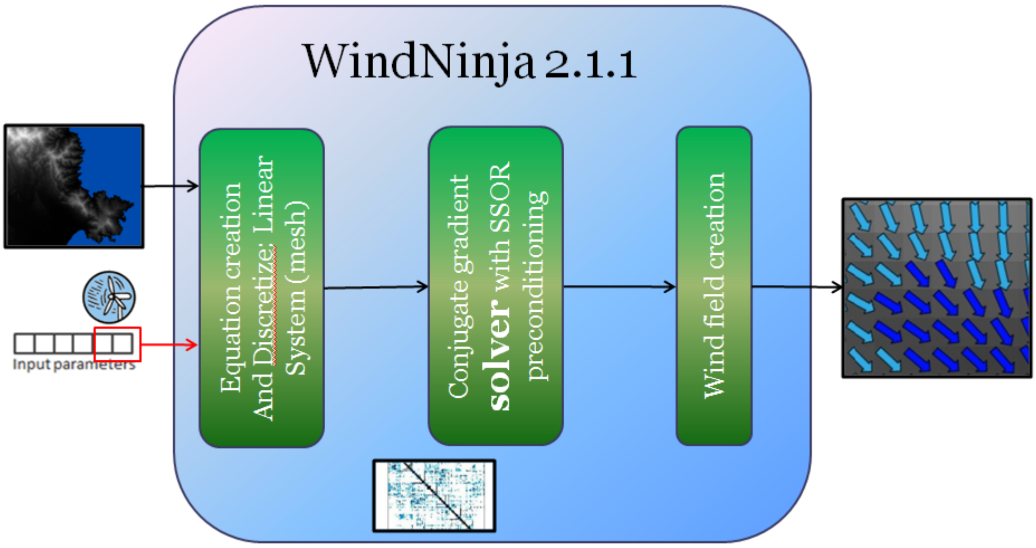


*Figure 2 –WindNinja*

To reduce the computation time of the wind field calculation a map partitioning method (Figure 3) has been applied to benefit from the parallel architectures. In this case the wind field is calculated in parallel on each part of the map and then the wind fields of the different parts are joined to form the global wind field. Furthermore, by partitioning the terrain map, the data structures necessary to calculate the wind field in each part are reduced significantly and can be stored in the memory of a single node in a current parallel system. Therefore, the existing nodes can perform computation in parallel with data that fit the capacity of the memory on each node.
However, wind field calculation is a complex problem that has certain boundary effects. So, the wind speed and direction in the points close to the boundary of each part may have some variability and differ from those they would have obtained if they were far from the boundary, for example if the wind field is calculated over a single complete map. To solve this problem, it is necessary to include a certain amount of overlapping among the map parts. So, there is a margin from the beginning of each part and the part cells itself. The overall wind field aggregation is obtained by discarding the calculated margin fields overlap of each part. The inclusion of an overlapping to each part increases the execution time, but the variation in the wind field is reduced significantly [8]. This map partitioning approach can easily be implemented in a Master/Worker MPI application where the Master creates the map parts and distributes them to the workers, the workers calculate the wind field for each part and return the results to the Master that aggregates the wind fields in a complete wind field. Once the map partitioning scheme has been applied, the resulting wind field map has the same dimensions as the original one.

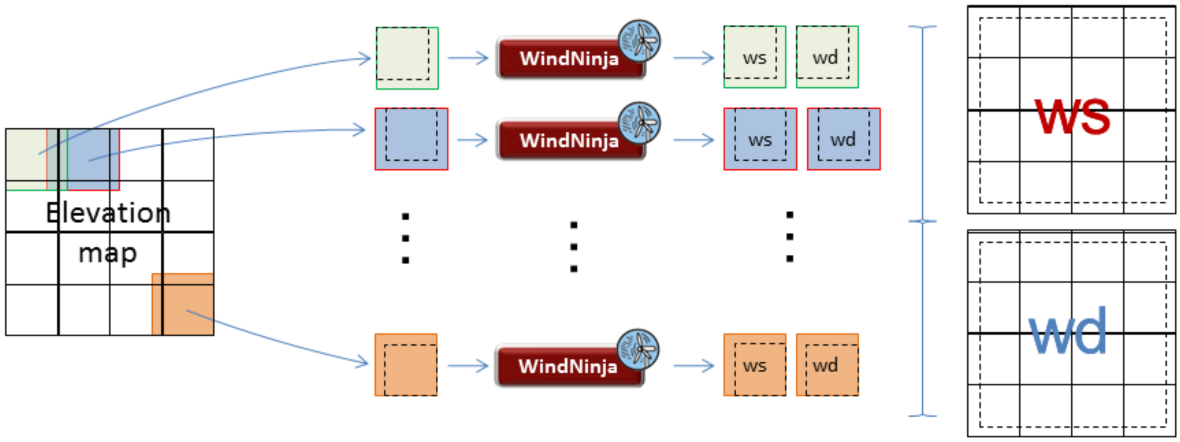


*Figure 3. Map partitioning*

The methodology has been tested with several terrain maps, and it was found that parts of 400x400 cells with an overlap of 50 cells (table 1) per side provides a reasonable execution time (120 sec) with virtually no variation with respect to the wind field obtained with a global map. With this type of partitioning, each process solves an effective part of a map of 300x300 cells. The inclusion of a wind field should improve the accuracy of forest fire propagation prediction, but it is necessary to test the effect of map partitioning on forest fire propagation prediction.

*Table 1- Similarity indexes for different partitioning*

| Speed (mph) | Partitioning | RSMESp (mph) | Speed >1 (mph) | MaxSp (mph) | RSMEAng ($^0$) |
|---|---|---|---|---|---|
| 5 | 6x6 | 0.191 | 8183 | 3.76 | 1.703 |
| 5 | 5x5 | 0.187 | 7818 | 3.76 | 1.571 |
| 5 | 4x4 | 0.188 | 7531 | 3.76 | 1.701 |
| 10 | 6x6 | 0.383 | 60920 | 7.50 | 1.703 |
| 10 | 5x5 | 0.373 | 49565 | 7.50 | 1.571 |
| 10 | 4x4 | 0.375 | 49182 | 7.50 | 1.701 |
| 15 | 6x6 | 0.574 | 156479 | 11.3 | 1.703 |
| 15 | 5x5 | 0.559 | 140826 | 11.3 | 1.571 |
| 15 | 4x4 | 0.563 | 140196 | 11.3 | 1.701 |

## 3. Effect of map partitioning on forest fire spread prediction

As it has been stated in previous section map partitioning does not generate extreme differences in wind fields, but it necessary to analyse the influence of such differences in forest fire spread prediction. To carry out such analysis it is necessary to execute a lot of propagation simulations considering maps with different topography terrains, different wind conditions, different vegetation types, different canopy covert and different fire positions. So, different terrain maps corresponding different areas of Spain has been selected. The raster maps used are composed by 1500 rows and 1500 columns with 30m resolution per cell. That means that the map has a dimension of 45km x 45km.
Tables 2 show the difference on burned areas for different types of vegetation (brush, grass, conifer and rough) and different map partitioning considering a meteorological wind of 15mph and a direction of 45º. This meteorological wind has been considered because it is the winds that generate larger differences in wind field. For each configuration, the evolution had shown in the time 24h. In particular, fire rows shows the results considering fire ignition points over terrain zones with a wind speed difference larger than 1mph, shows the results considering fire ignition points near the terrain point with differences larger than 1mph (it means that at some point of the propagation the fire front crosses that zones) and third rows shows the results considering fire ignition points far from those different wind speed zones (it means that the fire front does not cross those zones).

*Table 2- Difference for ignition point from different wind zones.*

| | 5x5 | | | | 15x15 | | | |
|---|---|---|---|---|---|---|---|---|
| | **Brush** | **Conifer** | **Grass** | **Rough** | **Brush** | **Conifer** | **Grass** | **Rough** |
| **Over** | 0.080 | 0.213 | 0.103 | 0.240 | 0.114 | 0.353 | 0.128 | 0.420 |
| **Near** | 0.063 | 0.035 | 0.072 | 0.051 | 0.073 | 0.047 | 0.096 | 0.069 |
| **Far** | 0.037 | 0.028 | 0.025 | 0.013 | 0.038 | 0.030 | 0.040 | 0.014 |

From the experiments carried out it can be observed that as the number of parts is increased, the error increases proportionally to that number of parts. This is due to the fact that the wind field generated when the parts are very small has a larger difference from the global map wind field and this larger differences provoke larger differences in fire spread predicted area.
On the other hand, it can be observed, as it was expected, that the position of the fire is very significant. If the fire does not cross points with significant wind speed difference the spread area difference is negligible. When the fire ignition point is on large wind speed difference zones the difference in burned area is larger, but not extremely different. These results are also presented in figures 4 that present an example of each one of the ignition point situation. In these figures the blue dots represent the zones with large wind speed difference, the yellow perimeter represents the Global Map Wind Field fire propagation, the red one represents the partitioning 5x5 map wind field fire propagation and the green

one the partition 15x15 map wind field fire propagation. In figure 4c it can be observed that there is no appreciable difference among the three perimeters. However, figures 4a and 4b show a small difference that is increased when the partitioning divides the map in more parts.
It must be considered that the show results were obtained considering that the fire only cross a large difference zone, but if there are several of such large difference zones on the fire area, differences in fire propagation prediction will be larger since the effects are accumulative.

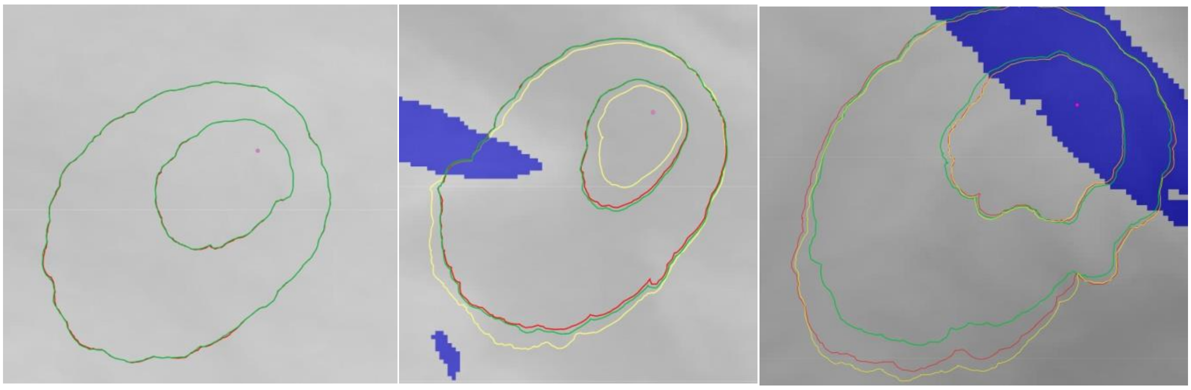

*Figure 4 –Propagation Fire*

## 4. Study case: La jonquera 2012

This analysis was carried out using as study case the fire that occurred in La Jonquera (Catalonia, Spain) in July 2012. In this case, the two-stage methodology has been applied considering 25 individuals per population and iterated for 10 generations. Since the Genetic Algorithm has a stochastic component the experiments have been repeated 3 times using different starting populations. For each case 4 fire fronts are compared:

- The real fire propagation.
- The predicted fire front obtained by considering a homogenous wind value along the whole terrain.
- The predicted fire front obtained by introducing a wind field calculated considering a complete map (1500x1500 cells).
- The predicted fire front obtained by introducing a wind field calculated by map partitioning (5x5 parts of 300x300 cells with 50 cells of overlap on each direction).

The results considered to determine the correctness of the approach are the following ones:

- The RMSE (Root Mean Square Error) estimates the difference among the wind speed (and direction) on each point of the terrain. The Root-Mean-Square Error (RMSE) is shown in equation 1. More precisely, for each map cell (N), the value of wind speed in that particular cell i obtained when no partition is applied to the input DEM map ($NP_{ws_i}$) is compared to the speed obtained in the same cell when applying the map partitioning strategy with a given partition scheme ($SC_{AXBws_i}$). The same procedure is also applied to wind direction just changing the corresponding terms of equation 1 to wd.

$$RMSE_{AxB}(ws) = \sqrt{\frac{\sum_{i=0}^{N}(NP_{(ws)_i} - SC_{AxB(ws)_i})^2}{N}} \quad (1)$$

- The Symmetric difference among the real fire perimeter and the fire front obtained by taking into account the three wind field schemes (homogeneous, complete map wind field and map partitioned field). This equation calculates the difference in the number of cells burnt between the predicted area by 2 different WindNinja configurations. In this case, the area predicted using a global map wind field (GMWF) is used as reference propagation. Formally, this equation corresponds to the symmetric difference between the global map wind field area (GMWF) and the partitioned map divided by the GMWF area, so as to express a proportion. ∪(GMCell,PCell) is the union of the number of cells burned in the GMWF and the cells burned in the partitioned map, ∩(GMCell,PCell) is the intersection between the number of cells burned in the GMWF propagation and in the partitioned map wind field, and GMCell is the number of cells burned using Global map wind field.

$$D = \frac{\cup\,(GMCell, PCell) - \cap\,(GMCell, PCell)}{GMCell} \quad (2)$$

- The execution time considering the complete 2 stage process.

### 4.1. Experimental results

Table 3 summarizes the results. It shows the wind speed RMSE and the prediction error and prediction times for each wind field scheme (homogenous wind, complete map wind field and partition map wind field) considering three initial population. It can be observed that the differences between the wind fields (RMSE) are very small and, on the other hand, the introduction of a wind field improves the quality of the prediction significantly. Comparing the homogenous wind propagation against the complete map wind field propagation the error is reduced between 20% and 35%. When comparing the homogeneous wind propagation against the partition map wind field propagation the error is reduced between 16% and 33%. This means that the map partitioning does not modify the fire propagation prediction significantly. However, the execution time of the two-stage process shows that the execution time to reach a prediction is significantly reduced when applying a map partitioning strategy. The time reduction varies between 47% and 70% which means a significant time saving.

| | RSMSE (mph) | Homogeneous Wind | | Complete map Wind Field | | Partition map Wind Field | |
|---|---|---|---|---|---|---|---|
| | | Pred. Error | Exec. Time (s) | Pred. Error | Exec. Time (s) | Pred. Error | Exec. Time (s) |
| **Pop. 1** | 0.14 | 0.74 | 255 | 0.59 | 967 | 0.62 | 295 |
| **Pop. 2** | 0.12 | 0.53 | 700 | 0.42 | 1407 | 0.35 | 739 |
| **Pop. 3** | 0.16 | 0.42 | 491 | 0.28 | 1195 | 0.33 | 530 |

***Table 3.- Comparison of wind field schemes***

The four fire perimeters for population 1 are shown in figure 2. The green perimeter represents the real fire propagation, the yellow one represents the homogenous wind fire propagation prediction, the red one represents the complete map wind field fire propagation prediction and the blue one the partition map wind field fire propagation.

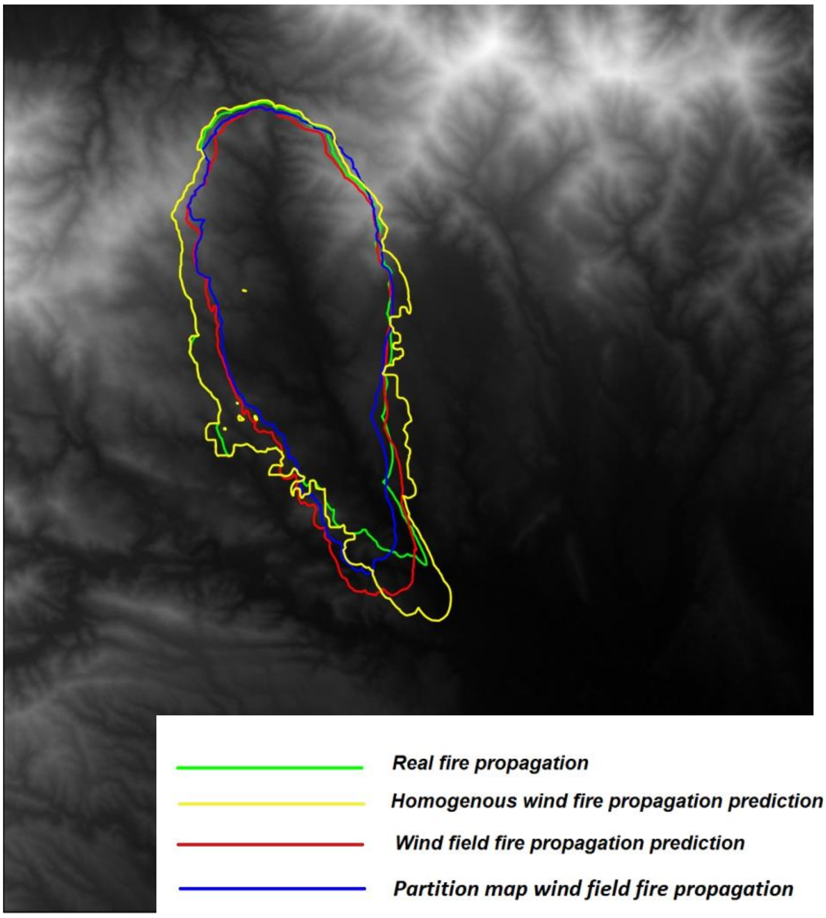


*Figure 5. Real and predicted fire perimeters*

## 5. Conclusions

Coupling wind field and forest fire propagation models is a promising approach to improve forest fire propagation prediction. However, such coupling demands high computing capabilities and takes long execution time. To overcome such difficulties a map partitioning approach has been defined to parallelise wind field calculation and reduce execution time. The results on synthetic and real fires show that the wind field and forest fire propagation prediction are not significantly affected by map partitioning and the parallelisation is effective.

## 6. Acknowledgement

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