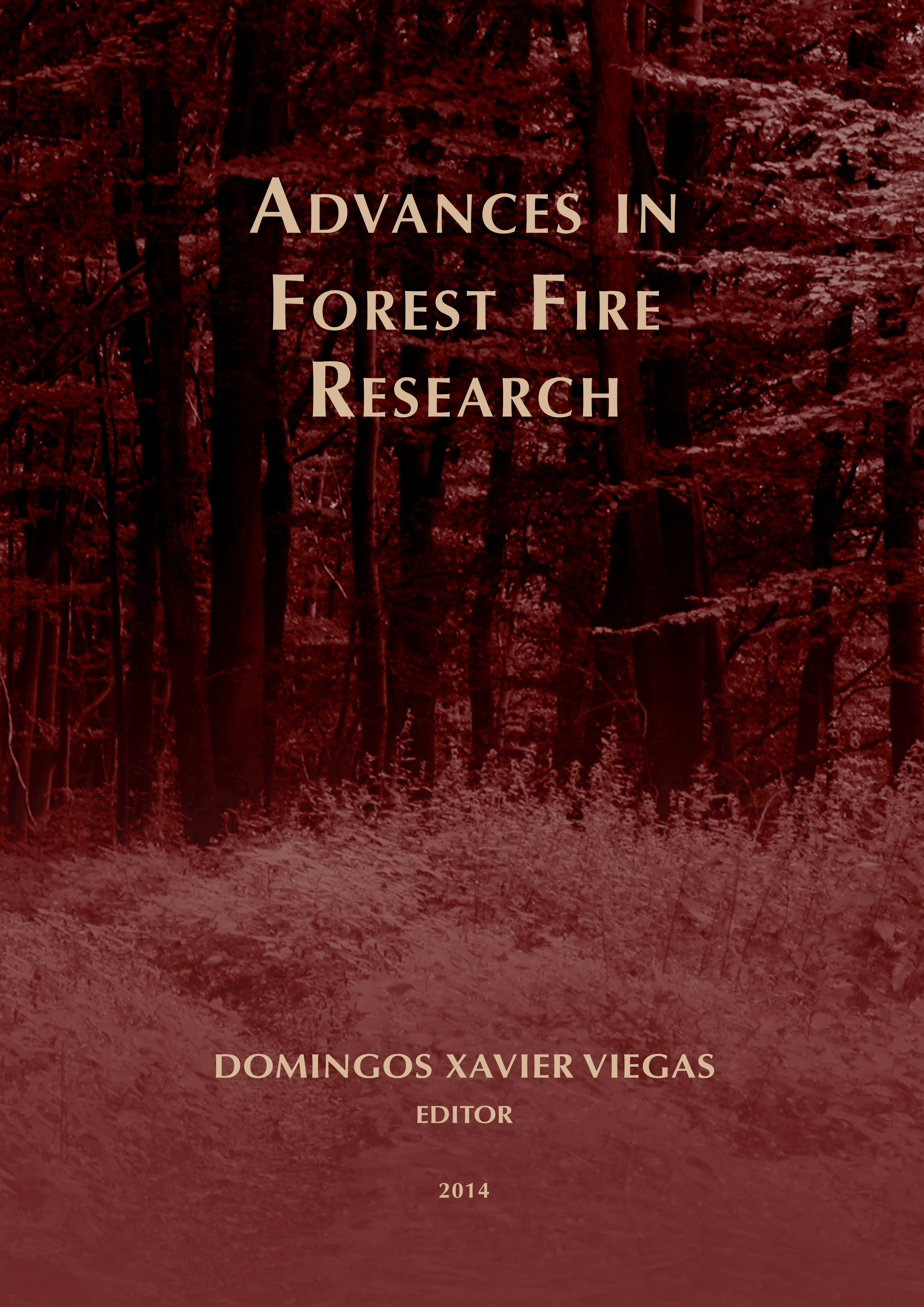

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The history of a large fire or how a series of events lead to 14000 Hectares burned in 3 days

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Abstract
The year 2013 was particularly negative with regard to forest fires in Portugal. Besides of the large burned area (around 141000 ha until October 15th, according to official data), for a small country, 8 firefighters and a Mayor lost their lives while fighting the fires. In this paper we try to describe the series of events that led to the burning of around 14000 ha in the Northern Region of Portugal, in an unusually short period of time, and in what was the largest fire of the civil year. This fire was to be known as the *Picões* fire. The work described here is based on a report ordered by the Portuguese Minister of Internal Administration, and is part of a larger study involving another large fire (in Serra do *Caramulo*, Central Portugal) and the analysis of the accidents that caused the death of the 9 referred persons.
Countryman's fire environment (1972) and the series of events that potentially led to the unusually large burned area for that region are described in this paper. Fire behaviour is also analysed, with the help of fire behaviour simulations produced for specific periods of the fire.

Keywords: *Large fires; extreme fire behaviour; fire behaviour simulation*

1. Introduction

The forest fire that occurred between July 8th and July 12th in the Northeast of Portugal, the *Picões* fire, burned around 2000 ha of forest stands and 12000 Ha of shrubland, making it the largest one that year. The fire spread across 4 Municipalities: *Alfândega da Fé, Mogadouro, Freixo de Espada-à-Cinta* and *Torre de Moncorvo* (Figure 1).
On July 8th 2013, at 14h44, a fire ignited on the right bank of River *Sabor*. The fire was controlled on that evening, at 20h53 with an estimated burned area of 180 hectares. During the night and the next morning two teams of fire-fighters stayed on watch, monitoring the extinguished fire line. Despite of the vigilance, at 14h00 of July 9th, the fire rekindled and spread, sometimes with extreme violence, until it was dominated very early in the morning of July 12th, leaving an area of approximately 14000 ha burned.
During the afternoon of July 9th the violent fire propagation, with episodes of extreme propagation, burned through 18km in little over 5 hours. Approximately ten of the fourteen thousand hectares burned in less than one day, between 14h00 of July 9th and 10h00 of July 10th.
The reconstruction of a large fire is a slow and meticulous process. For this particular fire all of the major actors involved were interviewed: Civil Protection Authorities, Fire Brigade Commanders, representatives from the municipalities, local inhabitants and others. Also, as a work basis, some important documents were used: the official ANPC (National Civil Protection Authority) Incident Reports and a technical report focusing on the restoration of the burned area, produced by the National Forest Service (ICNF, 2013). MODIS satellite data about the fire progression was obtained from the Joint Research Centre (JRC) of the European Union and the "*MODIS Active Fire and Burned Area Products*" from Maryland University (EUA).

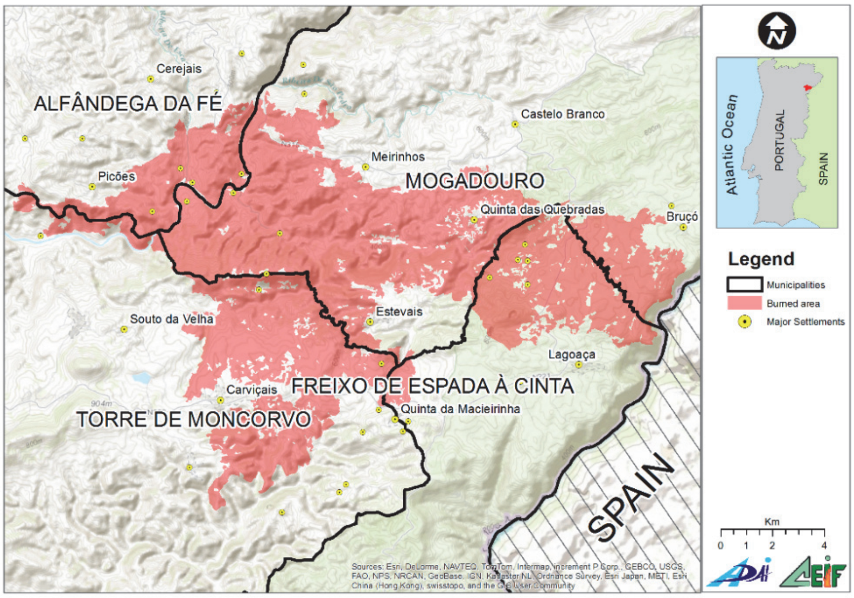


Figure 1. Burned area location, across 4 municipalities of the Northeast of Portugal

It was not possible to visit the area during the fire itself but we did it during October ($17^{th}/18^{th}$). In this visit we were also able to interview all the above mentioned intervenients.

2. Characterization of affected area

2.1. General characterization

The fire took place in an aged and low populated region, in a mountainous area where most of its inhabitants dedicate their few resources to subsistence agriculture and olive and almond trees. Some *Eucalyptus globulus L.* and *Pinus pinaster Ait.* stands are also present, maintained by the largest Portuguese paper pulp related company.

There are very few settlements in the region, as seen on Figure 1, and of small dimension. Many of them are named "*Quintas*" and consist of only 2 or 3 houses. Considering the fire perimeter and a buffer of 2000 meters outwards we counted 44 small villages and *Quintas.* The largest villages are on the margin of the fire perimeter.

The particularly rainy winter of 2013 had an important impact on the growth of fine fuels all over the country, but particularly in these areas due to 2 important factors. First, the construction of a big dam in the *Sabor* river was being finalized. In order to fill that dam all the vegetation (herbs, shrubs and trees) in the flooding area was being removed in the past months. During 2013 spring, all the basin along these main water tributaries of *Sabor* got covered with rapid growth herbaceous vegetation. Secondly, there is a common practice in the region of superficially ploughing two times the ground of the olive and almond fields, in early spring and in late spring/early summer, basically to remove all herbaceous fuels. The later was not possible, due to the high levels of moisture in the ground. These fields, usually good passive defense areas against fire, ended up with an unusual load of fine fuels. Apart from the described areas, most of the region is covered by shrubs.

2.2. Fire defense related infrastructures

The road network is not very dense, a common pattern found in many mountainous regions of the interior. The main roads (Municipal Roads) usually connect the municipalities' major villages or cities. In the area affected by the fire we found the Forest Road Network to be deficient, not covering most of the area. This aspect is a constraint when managing heavy firefighting vehicles and their positioning, as they have to travel for long distances. With very few exceptions there is one fire brigade per municipality and usually distancing more than 20 km from each other.

The closest brigades from the fire origin were from *Alfândega da Fé* and *Torre de Moncorvo*, approximately 10 km in a straight line.
The first crew to arrive to the fire, composed of 5 men, was transported by helicopter and arrived at the scene 10 minutes after the initial alarm. The ground crews (2 vehicles, 10 men) took 20 minutes.
The water sources or points used by the fighting crews are depicted in Figure 2. There's a main river (4^{th} order) on the East side (*Douro River*) but the orography of the surroundings makes it difficult for the aerial means to use it as a water source. The same for *Rio Sabor* (3^{rd} order), crossing the area from North to West. Besides these two rivers there are only 2 water sources for aerial means identified in the Municipal Defense Plans Against Fires (PMDFCI) obtained from the municipalities. Also, considering a buffer of 2 km from the final perimeter we count 14 terrestrial and 9 mixed water points. We ignore the conservations and usability conditions of these water points.

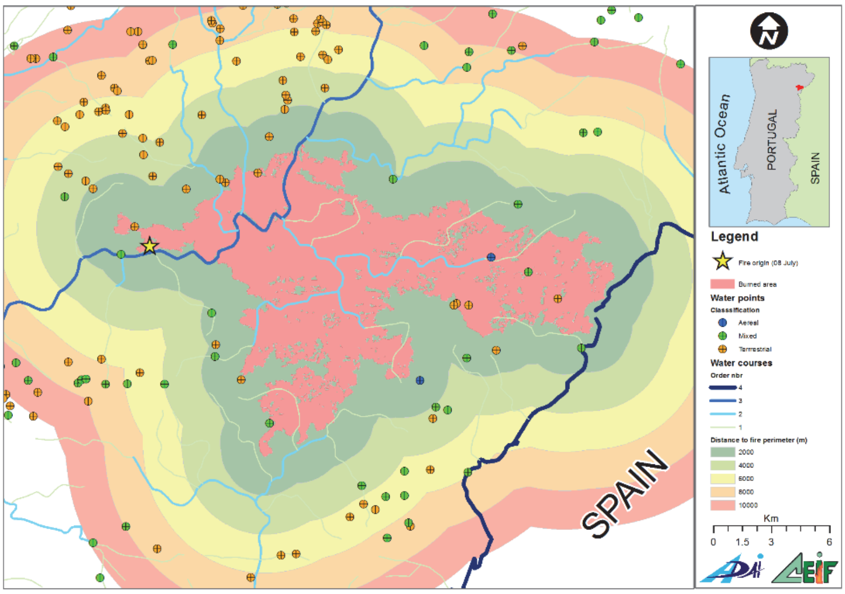


Figure 2. Water points in the area of the fire

Although not inventoried in the Plans, there are also a few dams of different dimensions in the surrounding, which we assume would have good operating conditions for the helicopters.
In such a large fire we consider the water resources to be scarce, even assuming they were all 100% operational. In the fire area itself there are practically no water supplies, and the large concentration of point on the Northwest was progressively being farther away as the fire progressed towards East.

2.3. Fire history

Knowing the fire regime of a particular area is of great importance for forest, fire and land managers.

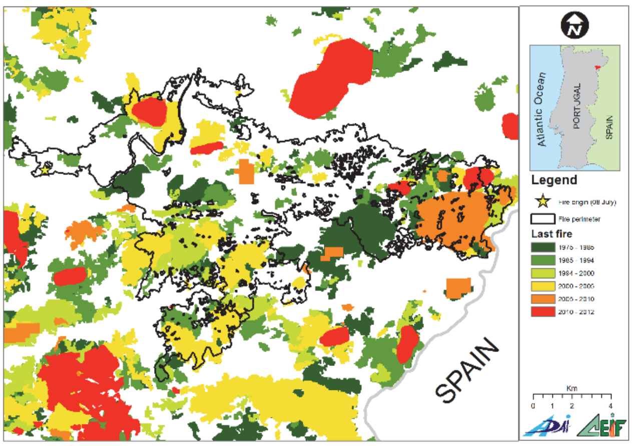


Figure 3. Last recorded fire in the region

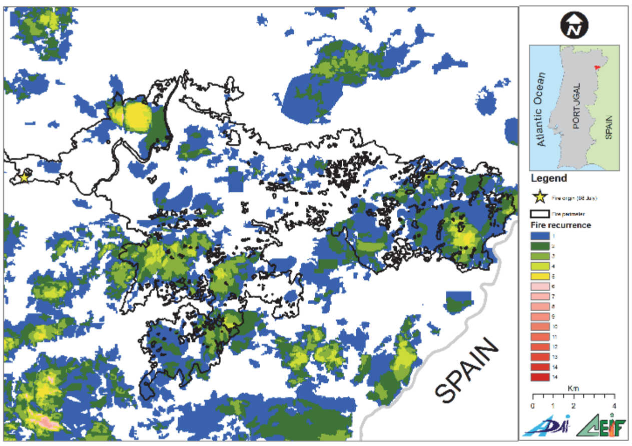


Figure 4. Fire recurrence in the region

In Figures 3 and 4 we can observe that a large portion of the area that burned in this event had not been burned since we have consistent and systematic records of fire perimeters in Portugal (1975).
The Southern part of the 2013 perimeter has burned between 1 and 4 times since 1975 but the last recorded fire was in 2005. The Eastern part has also been frequently affected by fire, some in 2010 and 2011.
The absence of fire in a large part of the region for the last decades, and the progressive abandonment of ancient agricultural practices results in an increasing accumulation of surface fuels, namely herbaceous and shrubs. This is a crucial factor in the increment of the fire potential in the region.

3. Fire environment

The fire environment is a well-known concept (Countryman, 1972) that describes the three main characteristics of the environment that affect the development of a forest fire: topography, fuels and meteorology.

3.1. Topography

The role of topography on fire spread is well known (e.g. Van Wagner, 1977; Pyne *et al*, 1996), namely the slope, by conditioning the rate of spread (ROS), or the orientation, by influencing the solar radiation received by the exposed fuels.
The area affected is mostly a mountainous region, with some open valleys mostly parallel to the wind and fire direction during the most important part of the fire development. The slopes are high in most of the area covered by the fire, in some cases greater than 45%, usually corresponding to the slopes that flank the rivers *Douro* and *Sabor* and their tributaries. A panoramic view of part of the area can be seen on Figure 5.

Figure 5. Panoramic view of part of the burned area

3.2. Fuels

Similarly to most of Portugal interior region, the predominance in this area in terms of land use is agriculture or related activities. However, the area directly affected by fire was mainly composed of shrubs and herbaceous vegetation. The municipal defense plans (PMDFCI) mentioned earlier are obliged to map forest fuels corresponding to a set of fuels derived from the standard American 13 NFFL fuel models (Anderson, 1982). Although there are technical guidelines published by ICNF the identification and mapping of these fuels is still very subjective as it relies on the knowledge and analysis of the different end users (the personnel responsible for the field work and cartography). Figure 7 is a composite of the individual fuel maps obtained from the municipalities. Even visually it is possible to see the lack of uniformity (Figure 6). Not only the resolutions used were different but also there are many cases where the same fuels are mapped with different codes, which denotes different identification criteria.

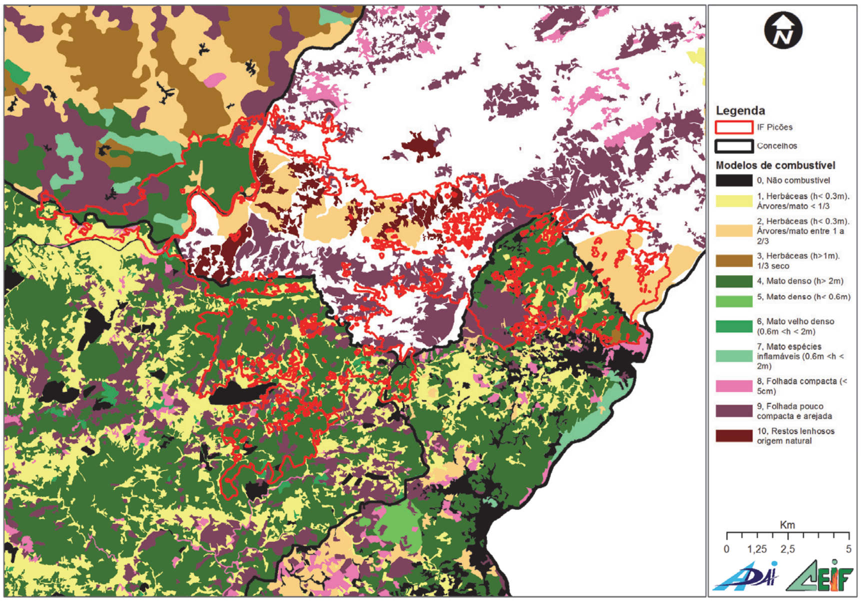


Figure 6. Fuel map of the area affected by the fire

In the surroundings of the ignition zone the prevailing fuels were described as natural herbaceous vegetation and dense shrubland (models 2 and 4). In this type of fuel bed fire spreads very rapidly and the existence of some scattered woody fuels increments its intensity. As the fire progressed to East herbaceous fuels dominate the landscape on the margins of the water courses. Apart from that, the majority of the central region of the fire was dominated by shrubs of different heights and loads (Models 4, 5 and 6). In these models fire propagates rapidly and intensely, even with high moisture contents. There are some forest stands, mainly composed of *Pinus pinaster Ait*. and *Eucalyptus globulus* L..

Very few fuel management activities were identified in all the region affected by the fire and the surroundings. The only management activities carried during the last 3 to 4 years were on the sides of some major roads and along the high and very high tension power lines. It was clearly not enough and not planned in a fire management perspective. Fuel moisture for fine fuels was estimated to be around 7% between 14h00 and 16h00, doubling during the night.

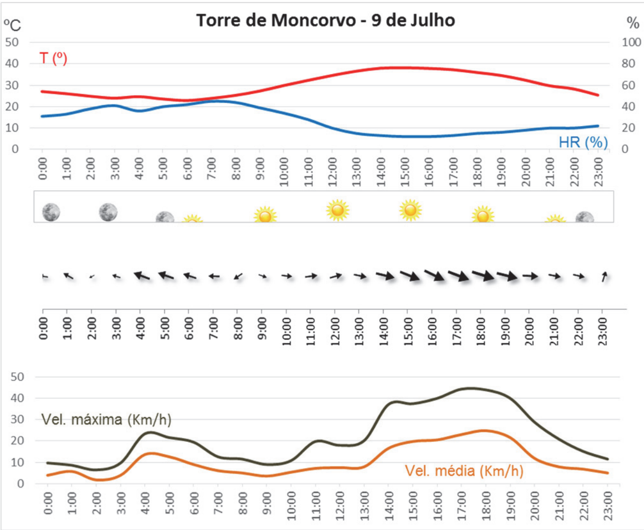
3.3. Meteorology

The year 2013 began with precipitation values above the average (IPMA, 2013a) until the end of May. June and July were below the climatic mean for the period 1971-2000.

According to the Portuguese Institute for the Sea and Atmosphere (Novo *et al.*, 2013; IPMA, 2013b) on July 3rd a heat wave affected Portugal, staying in the Northeast until July 13th. The precipitation on July was half of the mean value in almost all the country, with the exception of the Northwest.

Between 11th and 18th July some atmospheric instability was present in the North of the Iberian Peninsula, originating periodic episodes of light rain and thunderstorms.

To describe the period from July 8th to 11th, during which the fire spread, we used the meteorological stations owned by IPMA that are located very close to the affected area. One example of the constructed meteograms is shown on Figure 7.



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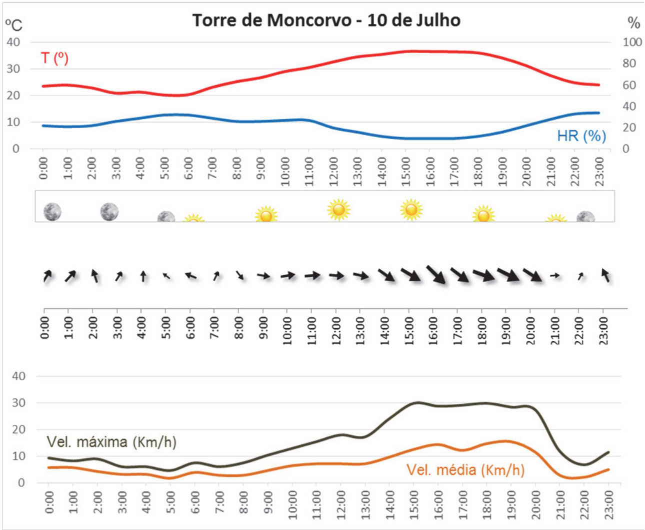

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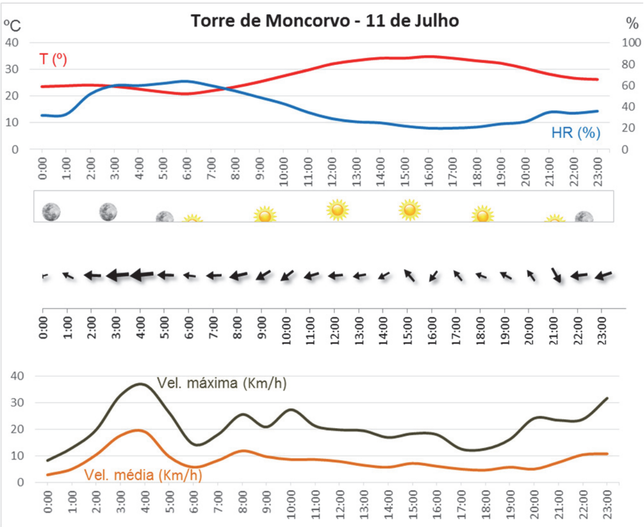

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Figure 7. Meteorological data recorded for July 9 (a), 10 (b) and 11 (c)

The recorded values are good reference but may not coincide with the ones registered locally on the different fire sections, mainly due to topographic effects and also to the influence of fire itself.
The values show 3 very hot days with maximum temperatures up to 40ºC and minimum above 20ºC. Relative humidity was also extremely low during the afternoons (around 10%).

3.3.1. July 9th

During the night and morning of July 9th, the wind always presented values of low speed, usually of the order of 5 km/h. During the night the wind was from the East shifting to West during the morning. At night high temperatures between 23 and 27 °C were recorded, together with relative humidity often less than or equal to 40 %.
Between noon and two o'clock the weather worsened. At 14h00 temperature was around 38 °C and humidity of 13%. The wind blew from W-NW with an average speed of 17 km/h and gusts of 37km/h. These values provided a rapidly developing fire after its rekindle. Throughout the afternoon wind speed varied from 17 to 25 km/h with gusts up to 44 km/h. The maximum values were recorded between 17h00 and 19h00, when the village of *Quinta das Quebradas* was hit by the fire.
At the beginning of the night the wind rotated to the South and its intensity decreased to around 5 km/h.

3.3.2. July 10th

During the night of July 10th the wind was from the South. Early in the morning started blowing from West and it increased the speed as the day passed.

At around 14h00 the wind shifted to Northwest and throughout the afternoon the wind remained with velocity varying between 10 and 15 km/h. Starting from 20h00, there has been a pronounced decrease in wind speed to values of around 3 km/h.

3.3.3. July 11th

The night from July 10th to July 11th brought increased wind intensity, unlike the previous two nights that had been very calm. Wind came from the East with gusts up to 40km/h. During the morning speed decreased to 10 km/h, maintaining direction, until it shifted to the Southeast at 15h00.

At the end of July 9th and 10th, in particular to the middle of the afternoon, the wind was weak, rarely exceeding 10 km/h. Under these conditions, in a region of complex topography and with the observed intense insolation, the local effects are dominant. Thus, the extrapolation of the wind behaviour from one location to another is subject to a certain degree of uncertainty.

4. Fire Chronology

4.1. The *Cilhade* fire – July 8th

At 14h44 of July 8th a fire started near a small uninhabited Quinta named *Cilhade*, in the municipality of *Torre de Moncorvo* (*Bragança* District). In less than 10 minutes after the initial alert, the initial attack crew was on the ground fighting a fire that was developing in a highly sloped area.

The fire burned about 180 hectares, according to our reconstitution (Figure 8). This fire was dominated in the early evening (20h53) the same day and the consolidation and mop up were initiated shortly after. During all night and the following morning two crews from the fire brigades involved in the extinction operations remained in the area on surveillance.

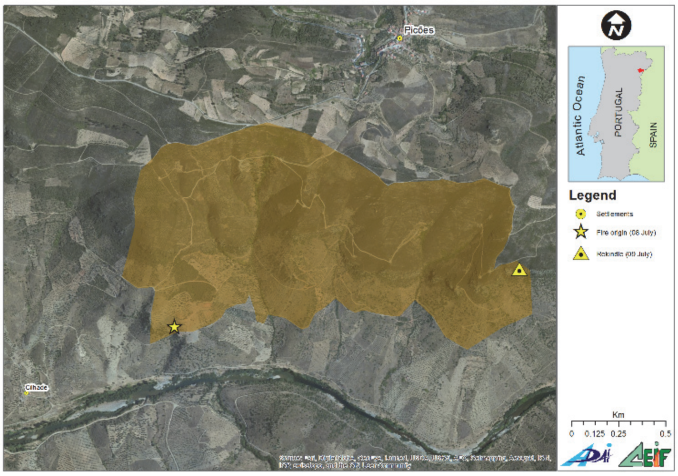


Figure 8. Approximate perimeter of the Cilhade fire on July 8th

4.2. The *Picões* fire – July 9th

Despite the vigilance operations, around 14h00, the *Cilhade* fire rekindled and quickly spread by adjacent sloping areas covered with shrubs. At this time the nearest weather station maintained by IPMA (*Torre de Moncorvo*) recorded temperature values of 38ºC and relative humidity of 13%.

The fire progressed rapidly to the East/Northeast, with the wind blowing from the West at an average speed of about 20 km/h but with gusts reaching 40 km/h. Due to the construction of the *Baixo Sabor* dam almost all the area across the river valley had been cleaned out of vegetation in the last months. The rainy spring of 2013 resulted in the growth, above average, of herbaceous vegetation, especially in these areas, which were relatively clean of trees and shrubs. The orientation of these areas, which would be filled with water when the dam started operating, is a perfect match with the general propagation of the fire in its initial stages.

At approximately 15h30 we estimate that the fire jumped to the left bank of the river *Sabor* (Figure 9).

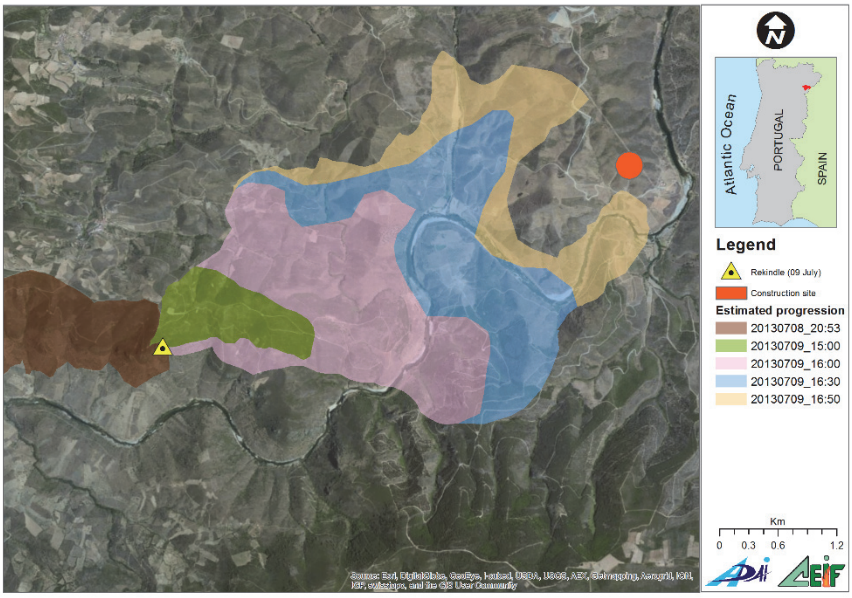


Figure 9. Estimated progression at 16h50 of July 9th

At around 16h50 a request for help was received from the chief of a construction site (marked in orange in Figure 9) who felt was being surrounded by fire, along with 30 workers. This call for help had a direct impact on the firefighting strategy. Although the fire officers had the perfect notion that the construction site was a safe place (that particular mountain had been cleared of vegetation from the middle to its top) they made the decision to displace several crews to evacuate the construction workers.

Between 17h00 and 17h30 the fire entered the long valley of a small water line called *Ribeira do Medal* and spread with a high velocity for about 3.5 km in a Northwest-Southeast orientation. It then split and entered the valleys of 3 other water lines (*Meirinhos*, *Resinal* and *Inferno*), as shown in Figure 10. The orange arrows show the direction of the fire propagation. Eventually the fire also spread North through another smaller water line.

The configuration of the terrain and the waterlines pushed the propagation of the fire towards the existing settlements, mainly *Meirinhos*, *Estevais* and *Quinta das Quebradas*. Also the wind was blowing from the West, which increased the ROS.

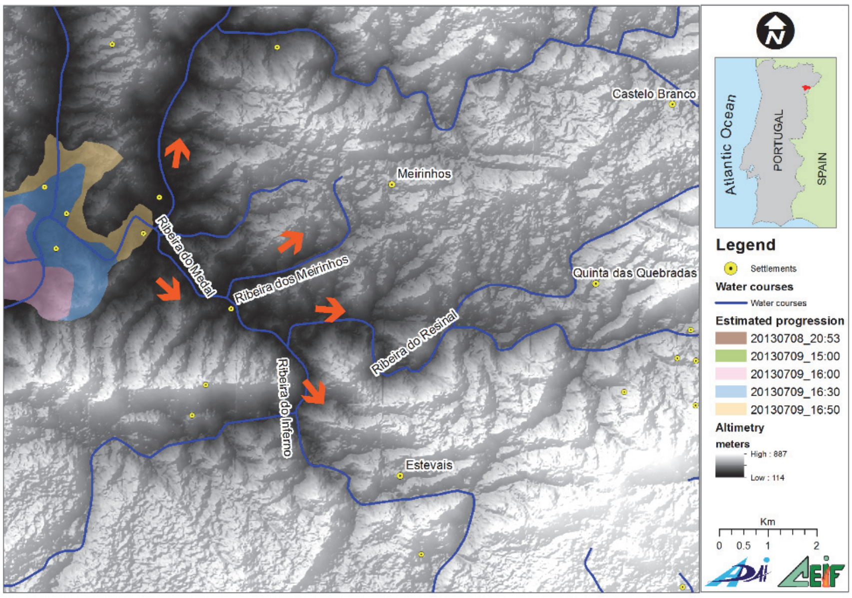


Figure 10. Scheme of the topography, water lines and direction of fire propagation

Around 17h30, with the fire progressing with unusually high rates of spread one of the fire Brigade Commanders identified the small village of *Quinta das Quebradas* as a priority target for defense, as it was located ahead, and on the most likely path, of the fire front. Although the fire front was approximately 6 km away, taking into account the observed ROS and the knowledge about the poor road network, it was decided to allocate some firefighting resources to protect the houses and people still there.
Between 17h00 and 19h00 the wind was blowing with an average of 20 km/h but with gusts up to 40 km/h. The fire was progressing not only by surface but with a considerable amount of flying embers, creating numerous spot fires. One of them was registered flying about 3 km from the main front, originating a spot fire less than 3 km west of *Quinta das Quebradas*. Another one was registered 1 km South/Southwest of the small village around 19h00. Shortly after another one at Southeast. Figure 11 represents the estimated propagation on the afternoon of July 9th. The orange arrows indicate the approximate location of the described spot fires.

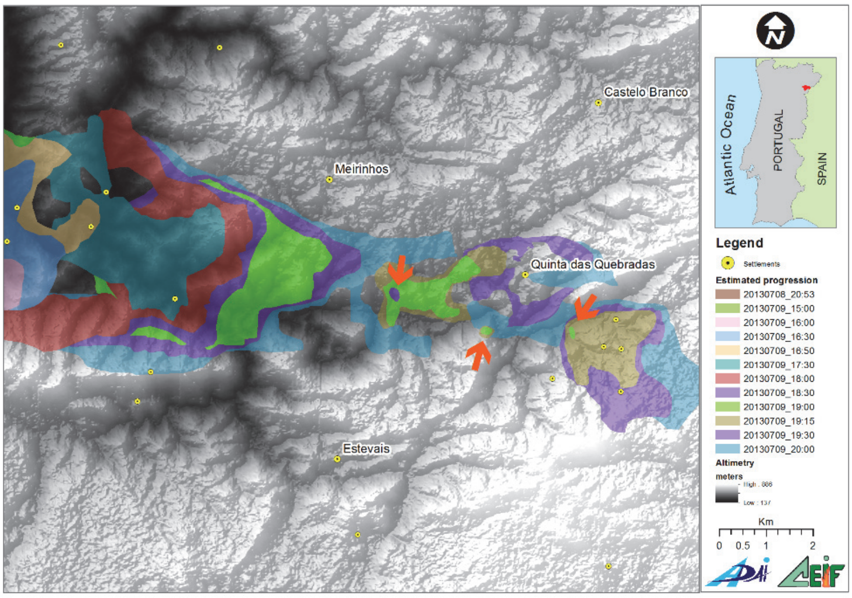


Figure 11. Estimated propagation on the afternoon of July 9th

The protection to *Quinta das Quebradas* was an important milestone of the fire as it coincided to the time of the most violent propagation of the fire, either by the rapid surface propagation and the numerous spot fires. By this time (around 19h00) 30 vehicles and 99 men were protecting the village and the fire was spreading freely. It even spread through the middle of the village.
The time from the decision of going to protect the village and the passing of the fire was of around one and a half hours. The fire spread through 6 km, which represents roughly 4 km/h, quite above the "normal" rate of spread.
The development of the spot fires helped accelerate the spread of the fire at this stage and lengthened it. Shortly after 19h00 traffic was cut on National Road EN221, which connects *Mogadouro* to *Freixo de Espada-à-Cinta*, about 2 km East from *Quinta das Quebradas*. At the end of the day, early evening, the wind calmed. Already in the early morning of the 10th, the front advancing Eastward stopped its progression on extremely steep slopes, often devoid of vegetation, leading down to the *River Douro*. One or two burning embers flew across the river and fell in Spain but were immediately extinguished by the Spanish firefighting crews.

The events that were just described, were the most important on the history of this fire, with a West-East axis of progression, perfectly aligned with the wind direction and most of the valleys and watercourses present in the area.

4.3. The *Picões* fire – July 10th

During the night (July 9th to 10th) the wind swirled South and decreased in intensity, registering speeds varying between 2 and 6 km/h and the fire began to expand laterally, with lower propagation speed. During the morning of the 10th the fire was progressing very slowly all over the perimeter. The prevailing wind was from the West once again with hourly average below 10 km/h.

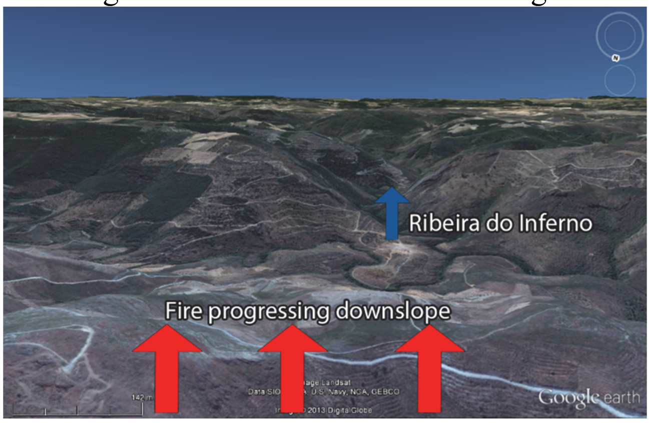


Figure 12. View from Google Earth of the fire going downslope into the Ribeira do Inferno

By late morning, a small section of the fire was spotted on the right flank, progressing downslope, and slowly heading to the valley of the *Ribeira do Inferno*. At this time the wind was weak and from the West but the forecast predicted a slight rotation to the Northwest accompanied by a small increase in speed. In low wind conditions and in the presence of a heat source (fire) the local effects induced by the topography in the wind dispersion are more pronounced.
Analysing the topography South of the region where this situation was detected, and knowing that the wind would be aligned with the valley of *Ribeira do Inferno*, it could probably be anticipated an increase in intensity and ROS of the fire as soon it reached the base of the slopes that are seen in Figure 12.
Indeed, around 14h00 on the 10th the wind increased in intensity and suffered a rotation to the Northwest. Virtually the entire left flank (North) and the back of the fire (West) were dominated or in mop up actions. Progression to East was contained in the *Douro* river. This change mainly resulted in the right flank gaining intensity and rapidly propagating South, in the direction of three small villages. By this time a large number firefighting crews and all available aerial means were dislocated to this area to protect the villages and its inhabitants, especially *Carviçais*, South of the fire. Figure 13 shows the estimated area burned at 22h00 of July 10th.

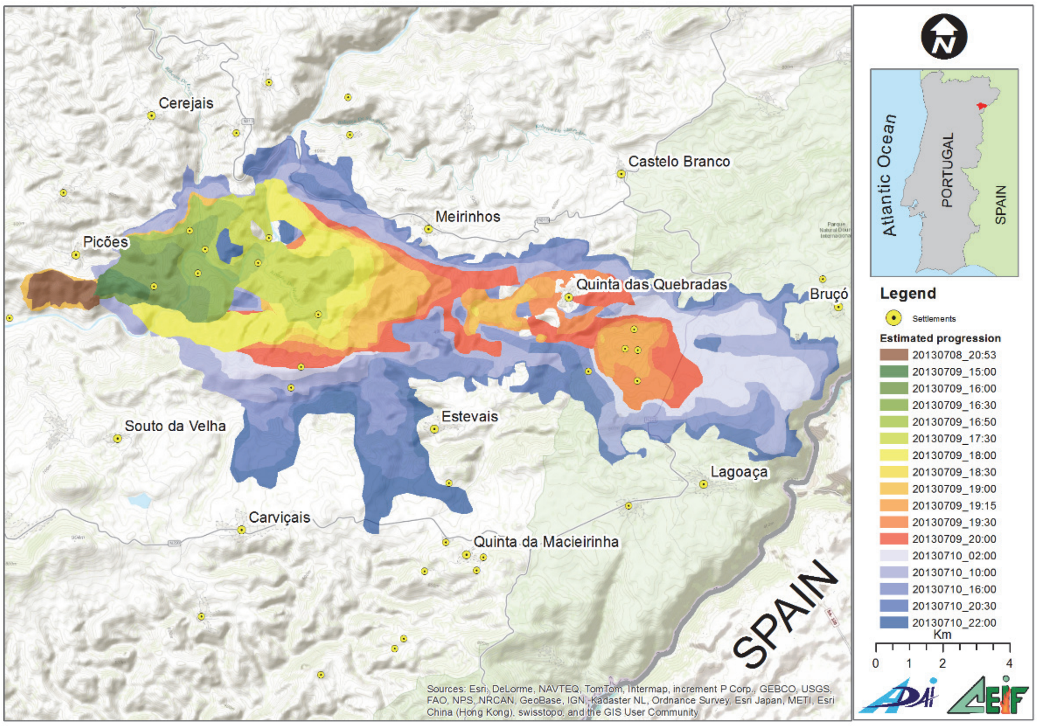


Figure 13. Estimated fire progression at 22h00 of July 10th

4.4. The *Picões* fire – July 11th and 12th

The morning of July 11th was not as favourable in meteorological terms. From 02h00 the wind increased in intensity prevailed from East, favouring the spread of the fire to the West. The average speed became of 15-20 Km/h with gusts of 30 to 40 Km/h.

The North area of *Carviçais* has an intensive and active agricultural occupation, posing as a natural barrier to the fire spread. There is also a major road crossing in an E-W direction, used as a support to the firefighting actions. Still, the fire jumped through in a small area occupied by shrubs. The wind changes that followed brought the fire, more than once, near the mentioned village of *Carviçais*, first in the North and then by South (Figure 14).

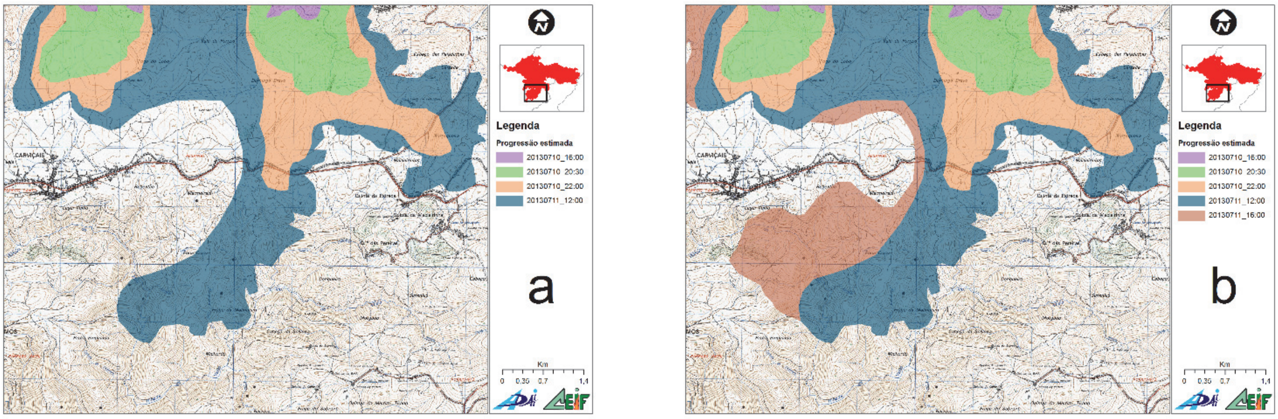


Figure 14. Detail of the estimated fire progression threatening Carviçais: at 12h00 (a) and at 16h00 (b)

During the night of 11th to 12th the prevailing East wind was of the order of 7-8 km/h and the fire did not propagate much more.

According to the Incident Report from ANPC the fire was finally declared extinguished at 09h30 on July 12th. The final burned area by registered ICNF was 13706 hectares, 1983 hectares of forest plantations and 11723 hectares of shrubland. Later on the final perimeter was released showing an area of 14136 hectares burned.

5. Analysis

5.1. Fire behaviour

The described fire evolution and its final burned area, depicted in Figure 16, were strongly affected by 3 major events: i) the rekindle of the original fire, ii) the defense of *Quinta das Quebradas* and iii) the wind shift that turned the right (South) flank into a fire front.

5.1.1. The rekindle of the original fire (beginning of the afternoon, July 9th)

The initial attack on the *Cilhade* fire was quick and effective. Given the location of the fire and the lack of good access road that hinders the arrival of heavy combat trucks, containing the fire in six hours and about 180 hectares can be considered a positive performance. Despite of the vigilance throughout all night and the next morning, at 13h47 the fire rekindled. This was probably the key element on the final outcome of the large *Picões* fire.

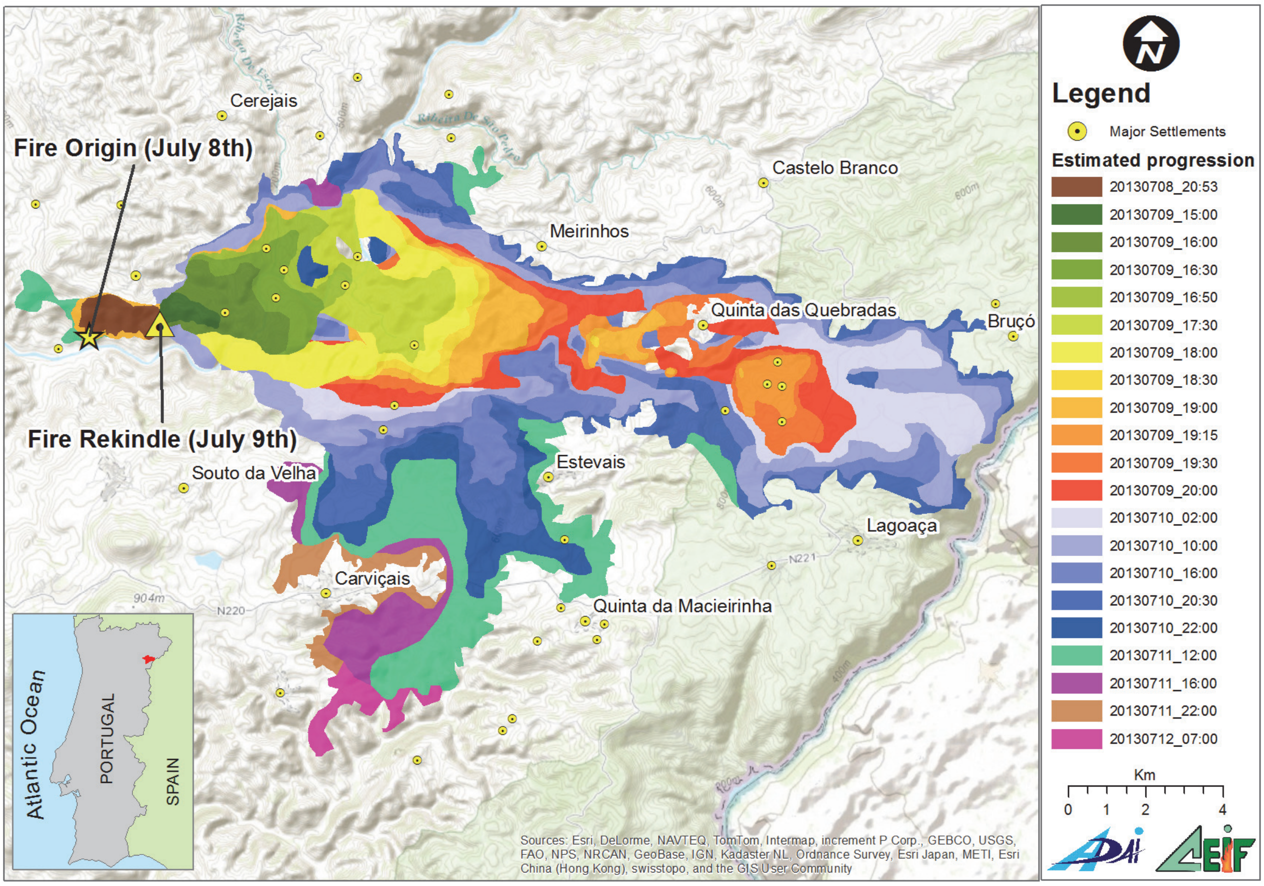


Figure 15. Global estimated fire evolution

Being able to predict changes in the wind field is extremely useful in fire management activities, especially if one is able to predict the influence of topography in its dispersion. IPMA provides atmospheric wind forecasts but using the fire behaviour simulator *Firestation*, developed in ADAI (Lopes *et al* 2002), we can simulate the effect of topography on the distribution of the wind field (Figure 16).

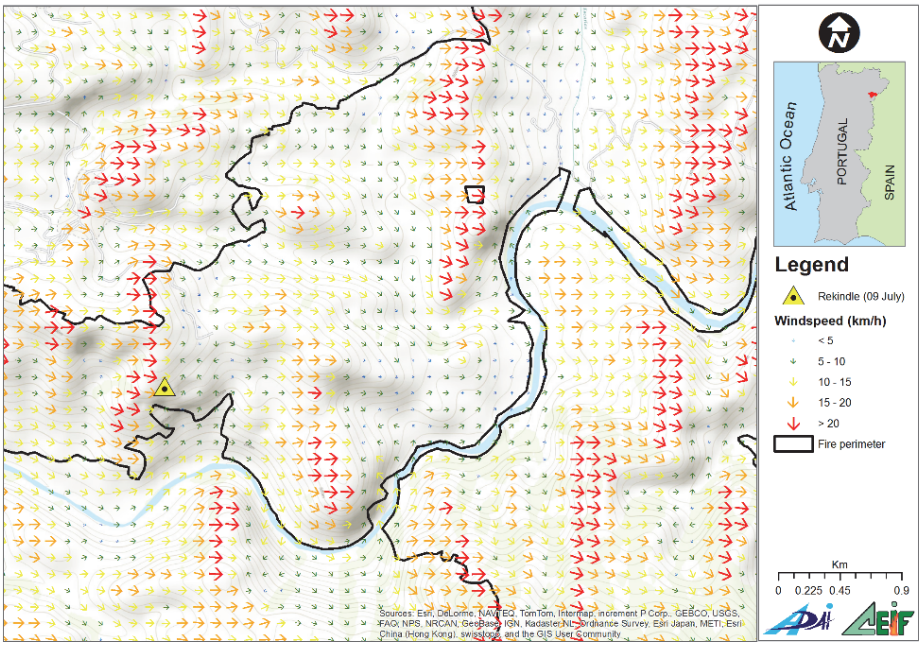


Figure 16. Simulated wind field at the time of the rekindle

At the time of the rekindle the West winds had higher overall speeds when going up the slopes facing West. The lower speed would be registered in the more sheltered valleys, with prevailing downslope East exposure. Jumping over river *Sabor* wouldn't have been hard as the strong winds easily carried burning embers across the valley. As described earlier, the herbaceous fuel load along the banks of the water lines was considerably high, as well as its curing degree. We assume the ROS at this early stage would have been very high. The air temperature was 38ºC and the relative humidity 13%. The surrounding area was still warm and the unburned fuels desiccated from the heat released from the fire of the previous day. When the fire started again it spread very quickly to adjacent fuels.
The alarm was not as swift as it should be and the initial attack on this rekindle was not strong enough to prevent the fire from spreading. In the first 3 hours of propagation the fire ran approximately 5 km in a W-E orientation (in a straight line) which corresponds to a mean rate of spread of 1.67 km/h. Figure 17 shows the vertical profile and the slope variation along the mentioned line of 5 km. Slope has several abrupt changes but sometimes is negative (fire progressing downslope). It is generally between 20 and 40%.

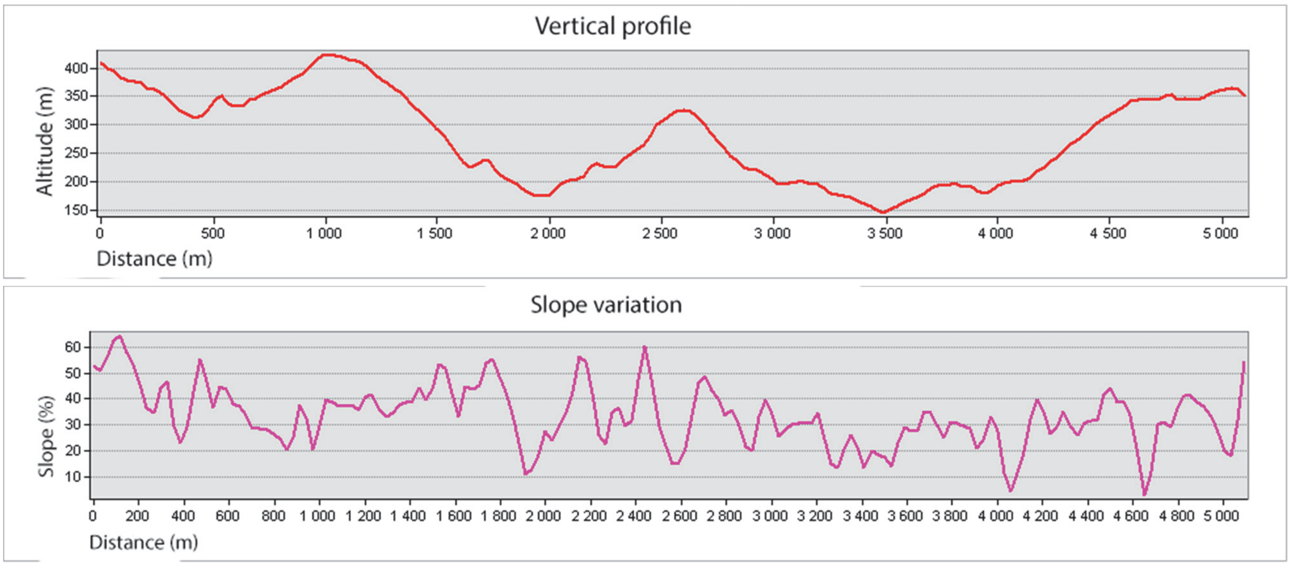


Figure 17. Vertical profile and slope variation in the first 5 km of fire spread (after the rekindle)

Using BehavePlus (Andrews *et al*, 2008) we estimated the fire rate of spread herbs and shrubs, in function of the slope and, assuming the slope is always positive, the predicted ROS was always below the observed (Table 1).

Table 1. Predicted ROS according to BehavePlus

Slope	%	20	30	40
Rate of spread (km/h)	Herbaceous	1.25	1.33	1.45
	Shrubs	1.05	1.10	1.19

From the middle of the afternoon the fire progressed with very high speed, not only through the surface but also with numerous spot fires.

5.1.2. The defense of the small Quinta das Quebradas village (late afternoon, July 9th)

During the afternoon of July 9th, and at the time of the most violent fire propagation, this village of around 100 inhabitants was stroke by the main fire front. At this time, in about one and a half hours the fire ran 6 km in a straight line, averaging approximately 4 km/h of ROS. Several spot fires were identified. There were practically no passive defensive structures around the village so, as it usually happens, firefighters stopped fighting the fire and concentrated on defending the structures, livestock

and, most important, the people living there. An important number of means were dislocated to this action: 30 vehicles and 99 men.
As the night progressed the meteorological conditions became more favourable and the fire slowed its W-E progression and eventually stopped on the steep scarps of river *Douro*.
At this stage the fire propagated very slowly on the flanks.

5.1.3. The wind shift that turned the right (South) flank into a fire front (morning, July 10th)

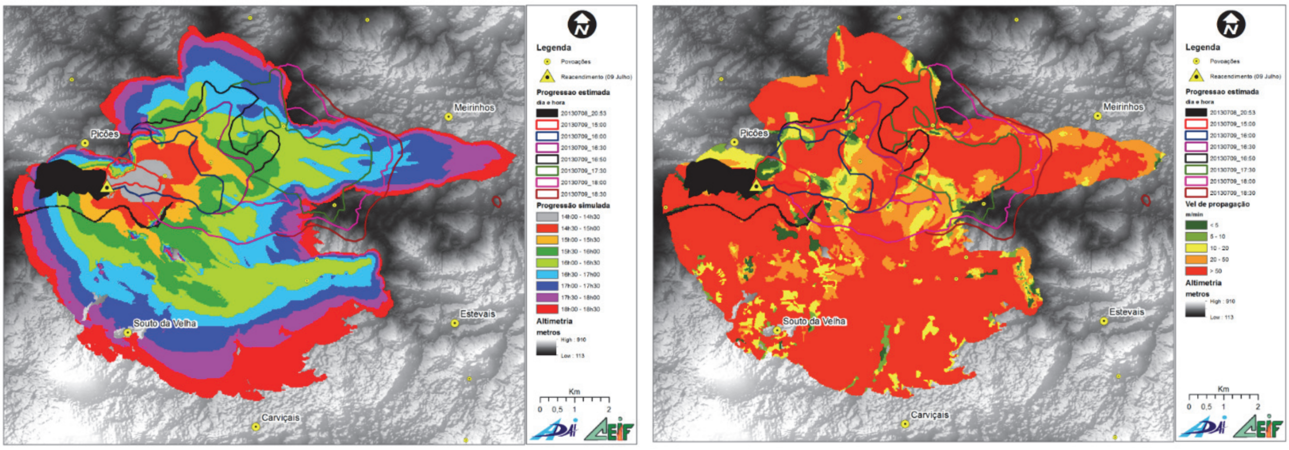
During the morning of July 10th the fire kept burning slowly on the flanks and the National Incident Command Structure in charge of the strategy believed it would soon be controlled. Despite the fact that wind predictions indicated a shift in the wind direction the overall strategy failed to adapt in time to the probable fire behaviour change. At the time the wind changed we estimate that the area burned should be around 8000 ha, far from the final 14000 ha. The fire was being pushed by slow Westerly winds into the East.
In the area identified and described earlier (see Figure 12) the fire was burning slowly and downslope, with the wind blowing sideways, but there weren't any firefighting crews nearby. In any fire, particularly a large fire, constant observation over the entire perimeter is of the utmost importance (either by terrestrial or by aerial means), as is the analysis of weather forecasts and topography and their expected influence on fire behaviour. We believe the reaction to the predictable wind shift was very late. We cannot tell for sure that, had this situation been anticipated, the fire would be contained, but evidence suggests that if the descending fire was attacked during the morning there was a strong possibility that it would be contained at this time.
After the wind has changed to the Northwest the right (South) flank of the fire became an active fire front and propagated to the South endangering some villages, one of them multiple times (*Carviçais* – see Figures 14 and 15).
During July 11th practically all manoeuvres were concentrated near *Carviçais*, where the fire reached from multiple points, as described earlier.

5.2. Fire behaviour simulation

Fire behaviour simulation is nowadays a very important tool in fire management, although a perfect knowledge of its fundaments and limitations is required. ADAI team has been developing a spatial simulation software called *FireStation* (Lopes *et al*, 2002), based on Rothermell's surface fire spread model (1972). The system takes as input static maps of fuels (obtained from the mentioned PMDFCI) and topography (in for of Digital Elevation Map) and point measurements of wind characteristics, that can be updated as needed. *Firestation* uses a wind simulation model called *Canyon* (Lopes *et al*, 1998), which is a model used for complex topography and that takes into account the different thermal and recirculation effects.
We chose 3 instants to simulate, corresponding to the 3 key events described earlier.

5.2.1. Phase 1 – the rekindle

For this first stage we used an ignition on the spot where the rekindle was identified. The area corresponding to the original fire was simulated as already burned, in order to avoid any interaction with the fire and wind simulation. Figure 18 represents the predicted and estimated fire progression for this period. Time since ignition and fire line intensity are shown.



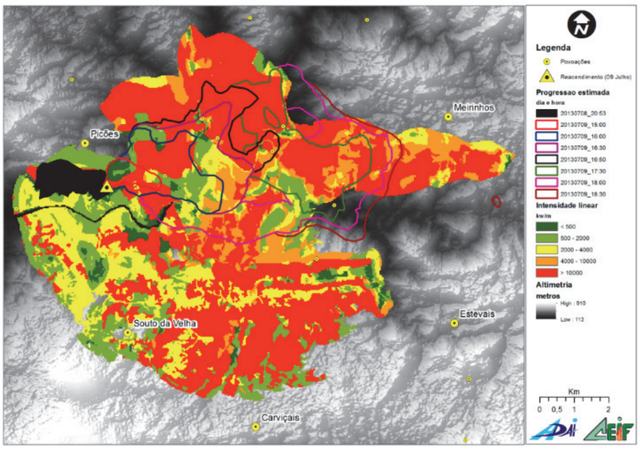


Figure 18. Predicted (Firestation simulator) and observed (estimated) fire propagation in the first hours after the rekindle: time since ignition (top left), rate of spread (top right) and fire line intensity (bottom left)

The coloured areas represent the simulation while the contours represent the observed (estimated) progression.

At a first glance we can see that the final shape of the simulated fire does not correspond to reality. Looking in more detail we observe however important results. The simulated fire has spread extensively to the South because it crossed river *Sabor* immediately after the rekindle and we know that that did not happen. We also know that, on the hill below the rekindle, the fuels were very scarce and the fuel map we used did not reflect that. Also the fuel map doesn't map the river in its whole, making fuels continuous from one bank to the other. This wrongly allows the fire to easily cross the river. If we limit the analysis to the Northern half of the simulation similarities with reality increase.

In the initial zone of fire propagation the simulated ROS exceeds 50 meters per minute (approximately 3 km/h), as seen in Figure 18. Moreover, according to the simulation, and with the exception of the period between the estimated progression of 16h00 and 16h30 (blue and violet lines), the entire area burned with ROS exceeding 50 m/min.

The intensity of a fire at the front can be related to the difficulty of attacking it and the probability of success, as shown in Table 2. Observing again the simulated fire intensity (Figure 19 - bottom left) we see that, during the first moments of the fire, its intensity could have been above 10000 kw/m, were any efforts to contain it would be virtually impossible.

Observing all these data we can assume that, after escaping initial attack, and with the few resources available in the field, the fire spread with a ROS that would make unfruitful any firefighting strategy

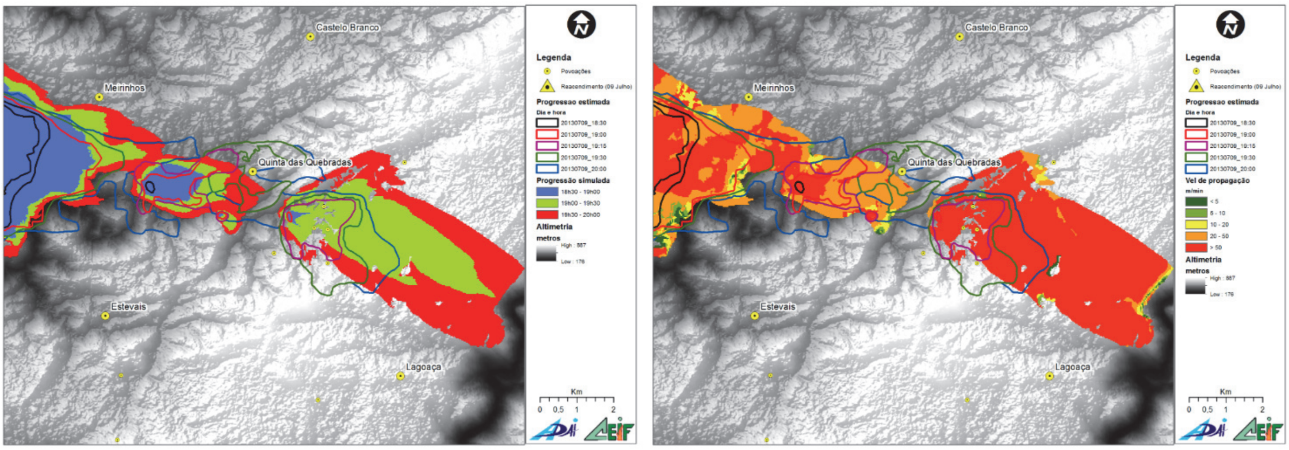
Table 2. Difficulty of fire control related to fire line intensity

Danger class	Fire Control	Fire line intensity (kW/m)	Fire suppression interpretations
Low	Relatively easy	I< 500	Direct attack at fire's head or flanks by firefighters with hand tools and back-pack pumps possible. Light aerial means effective.
Moderate	Moderately difficult	500 < I <2000	Firefighting along the flanks and eventually some spots in the fire front. Water is needed to control the fire. Medium to heavy aerial means can be effective
High	Very difficult	2000 < I <4000	Any attempt to contain the fire's head limited to the use of aerial means. Control efforts may fail.
Very High	Extremely difficult	4000 < I <10000	Suppression action restricted to back and flanks of the fire. Direct control of the fire likely to fail. Indirect attack with heavy aerial means. Spot fires expected to appear.
Extreme	Virtually impossible	I > 10000	Extreme fire behavior. Number of spot fires can increase rate of spread. Direct attack ineffective. Ground attack limited to flanks and back. But with low probability of success.

(adapted from Alexander & Lanoville, 1989)

5.2.2. Phase 2 – fire approaching Quinta das Quebradas

The ignition used for the 2nd phase was coincident with the estimated perimeter of the fire at 18h30 of July 9th, including the spot fire. The results are shown in Figure 19.



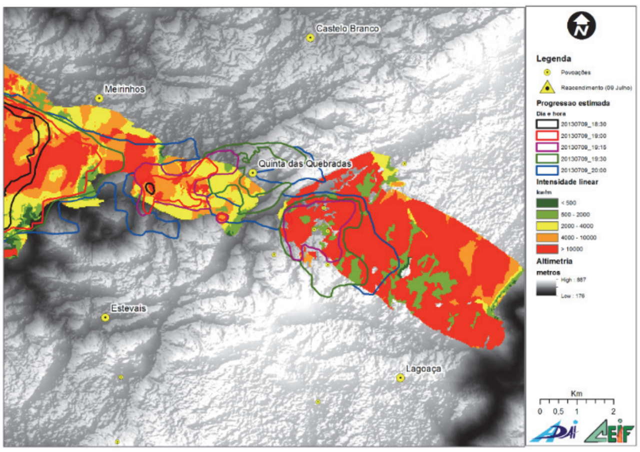
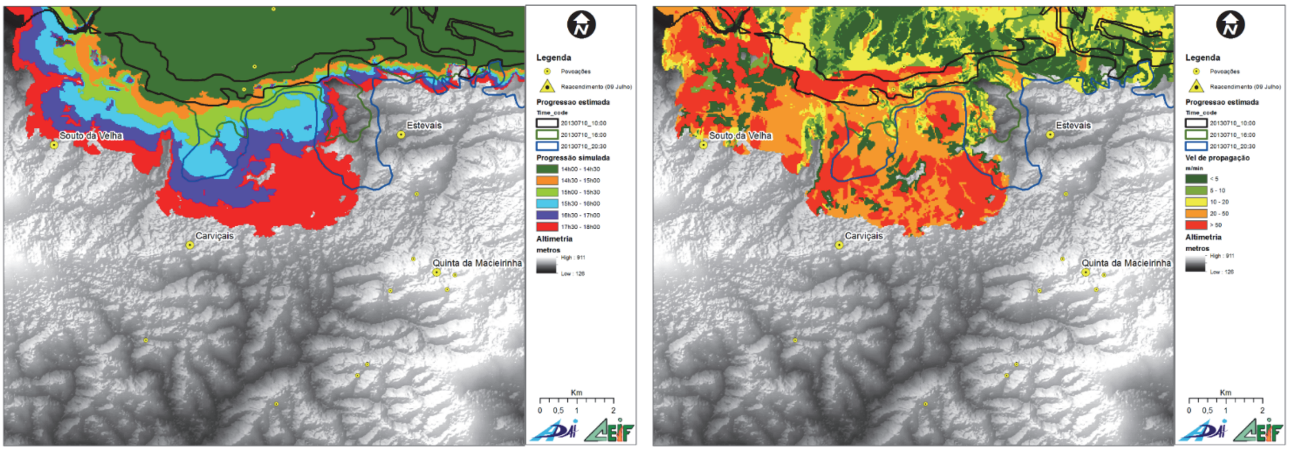


Figure 19. Predicted (Firestation simulator) and observed (estimated) fire propagation of the approach to Quinta das Quebradas: time since ignition (top left), rate of spread (top right) and fire line intensity (bottom left)

Simulation shows a fire intensity between 2000 and 10000 kw/m, with very few possibilities of a direct attack on the fire front. After passing through *Quinta das Quebradas* the fire gained intensity, mainly due to the change in fuels that were then dominated by shrubs.

5.2.3. Phase 3 – fire entering Ribeira do Inferno

The ignition in this phase corresponds to the area identified earlier when fire was progressing downslope (Figure 12) and at the time of the wind change. The simulation doesn't predict two fire "heads" but only one continuous front (Figure 21). Nevertheless the predicted rate of spread is above 20 m/min (1.2 km/h) and in a considerable area above 50 m/min (3 km/h). The higher values of intensity correspond to the fire entering *Ribeira do Inferno* and to the Southwest and Southeast of the simulated burned area.



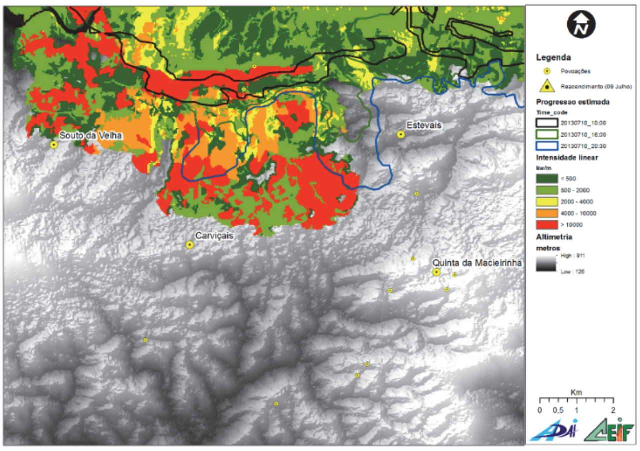


Figure 20. Predicted (Firestation simulator) and observed (estimated) fire propagation when fire entered Ribeira do Inferno: time since ignition (top left), rate of spread (top right) and fire line intensity (bottom left)

6. Conclusions and recommendations

The large fire of *Picões* had some moments in which any efforts from the firefighting crews to control it would not have been enough. There are 3 key moments, 2 of which with direct implications, that can explain the large area burned. The reconstitution we made is the closest possible to the real progress of the fire, although we admit that there may be some discrepancies with the actual progression. However, except for errors of detail, we believe to have recreated all the most important events accurately. The main conclusions we withdrew from this study were:

- The fire that occurred on July 8th in *Cilhade* was dominated and finished with an area of approximately 180 hectares burnt. After the mop up actions, surveillance was assured by teams who had already participated in the firefighting. These teams would perhaps not have the best state of mind and physical conditions to remain overnight and the following morning on surveillance. Vigilance was long because it was understood that, if there were any rekindle this would have to be controlled quickly under the threat of the fire gaining strength again. Probably would be a wiser decision to place new (fresher) crews on the vigilance. Despite of the vigilance, on July 9th around 13h47 a rekindle of this first fire occurred. This was the first key moment of *Picões* large fire.

- The rekindle took place in a difficult access to ground crews and at a time when weather conditions were particularly adverse. A rekindle usually develops faster than a starting fire even more with these weather conditions. Although we have no data to confirm this, we believe that it was not detected in time. The difficulty in accessing the area allowed the fire to rapidly grow in area and intensity.
- The population of the affected area has a high aging index, on average 2 times higher than the national average but in some regions gets to be 10 times higher. This aging results in some degree of abandonment of agricultural practices and a lower availability to implement self-protection measures near the urban centres. This is particularly noticeable in the small villages, like *Quinta das Quebradas*.
- The villages and *Quintas* are not in large numbers but they are disperse and their access is very difficult. The firefighting crews deployed to protect the buildings had great difficulty, not only in reaching there but also later on in reallocating to actively fight the fire.
- There's an enormous lack of self defense culture among the majority of urban areas, despite of their size, as well as in isolated houses. Not only by managers, or politicians but also by the inhabitants themselves. The major consequence is that in most cases fighting the fire becomes secondary for the crews, as they have to protect houses and people first.
- The construction of the *Baixo Sabor* dam was at a very advanced state of execution, as were the preparatory measures necessary before the filling. Much of the valleys in this region, especially the main water lines had already been cleared of shrubs and trees. A very wet spring of 2013 resulted in a substantial herbaceous production, all over the country but especially in those areas that were devoid of vegetation. The existence of a large amount of dry and cured grass favourably influenced the rapid progression of the fire, especially on day 9th.
- During the afternoon of July 9th the fire reached velocities much higher than what we consider normal fire behaviour. Between 17h30 and 19h00 the fire ran about 6 km towards East, reaching *Quinta das Quebradas* with great violence. The protection of this small village was the second key moment of the fire. A large number of human and material resources were required for the defense of people and their assets, consequently abandoning the combat against the propagating fire.
- Fuels management in the area affected by the fire was incipient. Almost no fuel breaks are present in the area and the ones that exist lack maintenance.
- The water points' network in the area was not adequate, requiring extensive travel for water refuelling.
- Data analysis about terrain and weather forecasting is of great importance in fire behaviour prediction, even without taking into account the fuel. During the morning of July 10th this prediction did not motivate a timely reaction by the Commanding Officers and this was the third key moment of the *Picões* fire.
- Expert fire behaviour prediction is still not being taken into account on normal fire management activities, and we believe this to be a gap in the system that should be filled.

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