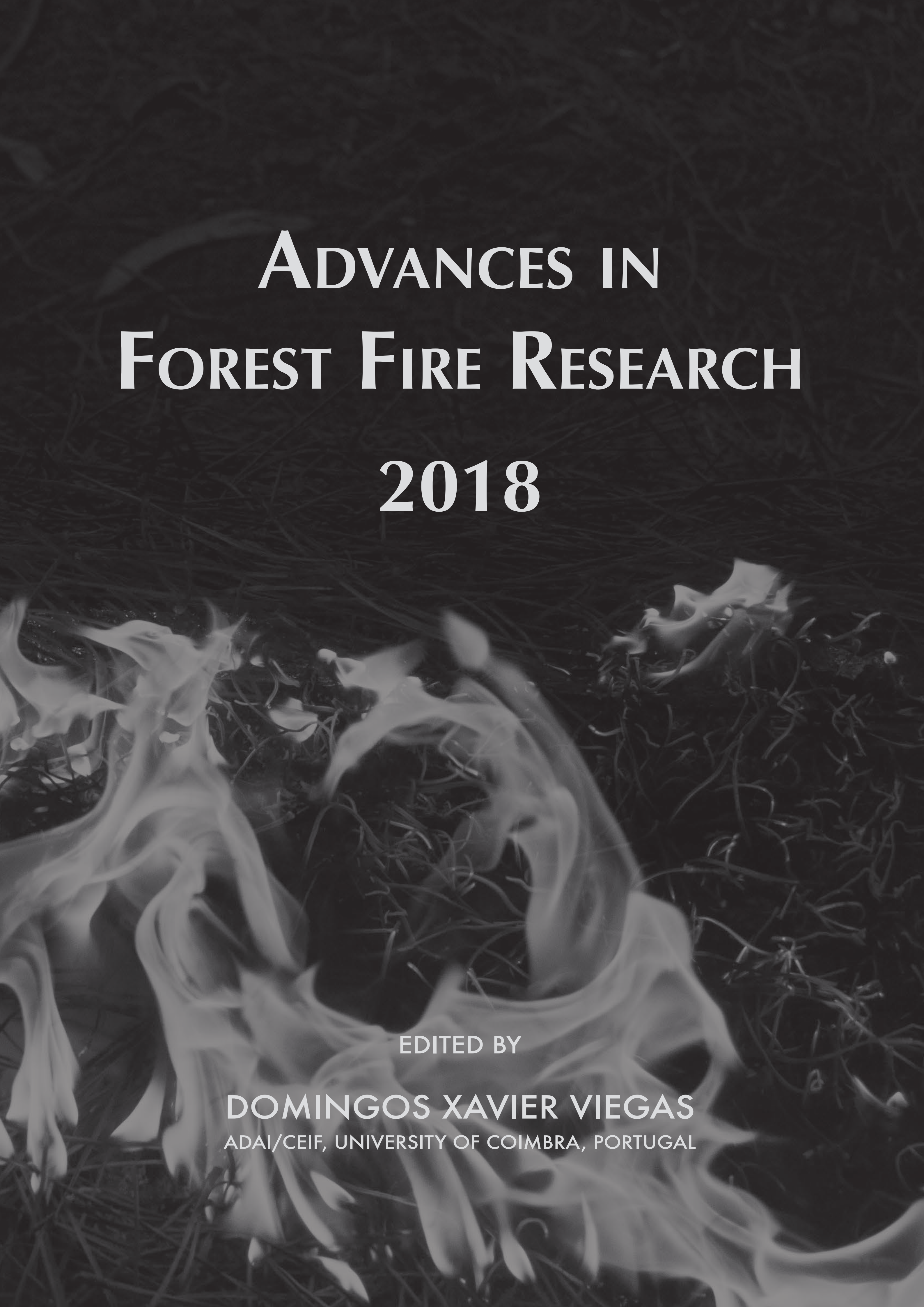

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# Fire growth patterns in the 2017 mega fire episode of October 15, central Portugal

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**Abstract**

Increasingly large fires are occurring in southern Europe, especially at its westernmost part, where a humid Mediterranean climate combines with rough topography, flammable vegetation types, undermanaged forest and high ignition rates. These fires have huge socioeconomic and environmental impacts, including the potential loss of human lives. Portugal was struck by an exceptionally severe fire season in 2017 that included a multiple mega fire event (~200 kha) in mid-October, unprecedented in Europe in terms of season and the extent of area burned in a very short period. This new phenomenon, arguably caused by climate change, needs to be characterized and understood to inform future fire management. We describe how five mega fires (or fire complexes) have developed in central Portugal on October 15-16, 2017, and assess their major drivers. We described fire weather through the Canadian FWI System, the C-Haines index and atmospheric profiles, retrieved weather data, and estimated fine dead fuel moisture content. Seven extremely large fire scars resulted from the October 15 event. We selected five of them (18,503-48,462 ha) for fire growth reconstruction. To describe fire spread we compiled data from various sources, including satellite imagery, official reports and fire suppression data, photos and videos, and people accounts. When satellite hotspots presented high density, the Fire Radiative Power of these points was interpolated to identify the approximate location and shape of the active fire front. We built a fire location chronology and interpolated the resulting points to support the final production of a map of hourly fire isochrones. For each hour period we calculated burned area and fire growth rate. Fire danger rating was Extreme, with most weather stations displaying FWI>50, expressing the joint effects of critical fuel aridity and hurricane Ophelia and its advection of warm and dry air from Africa. C-Haines index reached 10-11 (on a maximum of 13) and the moisture content of fine dead fuels was 3-6%. Forests comprised most (78%) of the burned surface, with Pinus pinaster generally dominating. Among fires, an average of 73% of the area burned for the first time since 1975 or had not experienced fire for the last 19 years or more, indicating potentially high fuel load. Fires spread followed the SW-NE axis and often crowned, with spotting as an important spread mechanism that allowed fire percolation through fragmented forest landscapes to impact important wildland-urban interfaces. Estimates of maximum hourly rates of spread varied from 5 to 9 km hr-1 between fires, corresponding to 50-90 MW m-1 for a typical fuel load. Initial fire growth was fast and dominated by strong winds and very low fuel moisture content. Wind subsided subsequently, relative humidity increased, and a sequence of pyro-convection events developed, coinciding with the fastest, and also erratic, fire spread periods. Overall, an average of 10,000 ha burned per hour between 16:00 and 05:00 of the following day. The findings from this reconstruction and the explanation of the events will assist in improved fire management policies and operational guidelines, from fuel management to fire preparedness and suppression.

**Keywords:** extreme fire behaviour, fire weather, pyroconvection, rate of spread

## 1. Introduction

Increasingly large fires are occurring in southern Europe, especially at its westernmost part, where a humid Mediterranean climate combines with rough topography, flammable vegetation types, undermanaged forest and high ignition rates. These fires have huge socioeconomic and environmental impacts, including the potential loss of human lives. Portugal was struck by an exceptionally severe and prolonged fire season in 2017 that included the deadly Pedrogão Grande fire in June, a significant number of very large fires (>5000 ha) throughout summer, and a multiple mega fire event (~200 kha) in mid-October, which was unprecedented in Europe in terms of season and the extent of area burned in a very short period. Comparable, but less severe previous events did occur in Spain (146 kha from the 2$^{nd}$ to the 9$^{th}$ of July 1994), Portugal (~100 kha, 1$^{st}$ to 2$^{nd}$ of August 2003), and Greece (63 kha in six days of August 2007). This is a new phenomenon, arguably caused by climate change, and needs to be documented, characterized and understood to inform future fire management policies and practices.

Here we describe how five mega fires (or fire complexes) have developed in central Portugal on October 15-16, 2017 and assess their major drivers. Implications for fire management are discussed.

## 2. Methods

We described fire weather through the indices of the Canadian FWI System (12:00 UTC), the C-Haines index and atmospheric profiles, retrieved air temperature, relative humidity and wind (speed and direction) data from the IPMA network of automatic weather stations, and estimated hourly fine dead fuel moisture content. Seven extremely large fire scars resulted from the October 15 event. We selected five of them for fire growth reconstruction, respectively the inland fires of Lousã (45,505 ha), Arganil-Seia complex (48,462 ha) and Sertã (32,356 ha), and the coastal fires of Pataias (18,600 ha) and Quiaios (18,503 ha). To describe fire spread over time we compiled and cross-referenced data from a variety of sources, including satellite imagery (MODIS, VIIRS), official reports and fire suppression data, georeferenced photos and videos, and people accounts. When satellite hotspots presented high density (typically because of strong wind or high flame residence time), the Fire Radiative Power of these points was interpolated to identify the approximate location and shape of the active fire front. We built a fire location chronology on Google Earth and interpolated the resulting points using Radial Basis Functions to support the final production of a map of hourly fire isochrones. For each hour period we calculated burned area and fire growth rate and estimated fireline intensity (FLI, kW $m^{-1}$) using observed meteorology and the fire spread rate resulting from those isochrones. Finally, to understand better driving factors of pyroconvection, we calculated the Pf and Pw numbers (Rothermel 1991) to assess weather fire was plume dominated or wind driven.

## 3. Results

Fire danger rating was Extreme on the 15$^{th}$ of October, with most weather stations displaying FWI>50, and a few at FWI>80, expressing the joint effects of critical fuel aridity and hurricane Ophelia and its advection of warm and dry air from northern Africa. C-Haines index reached 10-11 (on a maximum of 13) and the moisture content of fine dead fuels was 3-6%. Forests comprised most (78%) of the burned surface, with maritime pine (*Pinus pinaster*) dominating (50-97% cover), except in the Lousã fire, where blue gum (*Eucalyptus globulus*) prevailed (45%). Among fires, an average of 73% of the area burned for the first time since 1975 or had not experienced fire for the last 19 years or more, indicating potentially high fuel load.

Fires spread following initially the SSE- NNW axis to turn gradually to the SW-NE axis, when their maximum growth occurred. They often crowned, with spotting as an important spread mechanism that allowed fire percolation through fragmented forest landscapes to impact significant wildland-urban interfaces. Estimates of maximum hourly rates of spread varied from 5 to 9 km hr$^{-1}$ between fires, corresponding to 50-90 MW m$^{-1}$ for a typical fuel load of 20 t ha$^{-1}$.

Initial fire growth was fast and dominated by strong winds and very low fuel moisture content (Figure 1). Wind subsided subsequently (after 16:00), relative humidity increased, and a sequence of pyro-convection events developed, especially after 19:00, that coincide with the fastest, and also erratic, fire spread periods (Figure 1). Overall, an average of 10,000 ha burned per hour between 16:00 and 05:00 of the following day.

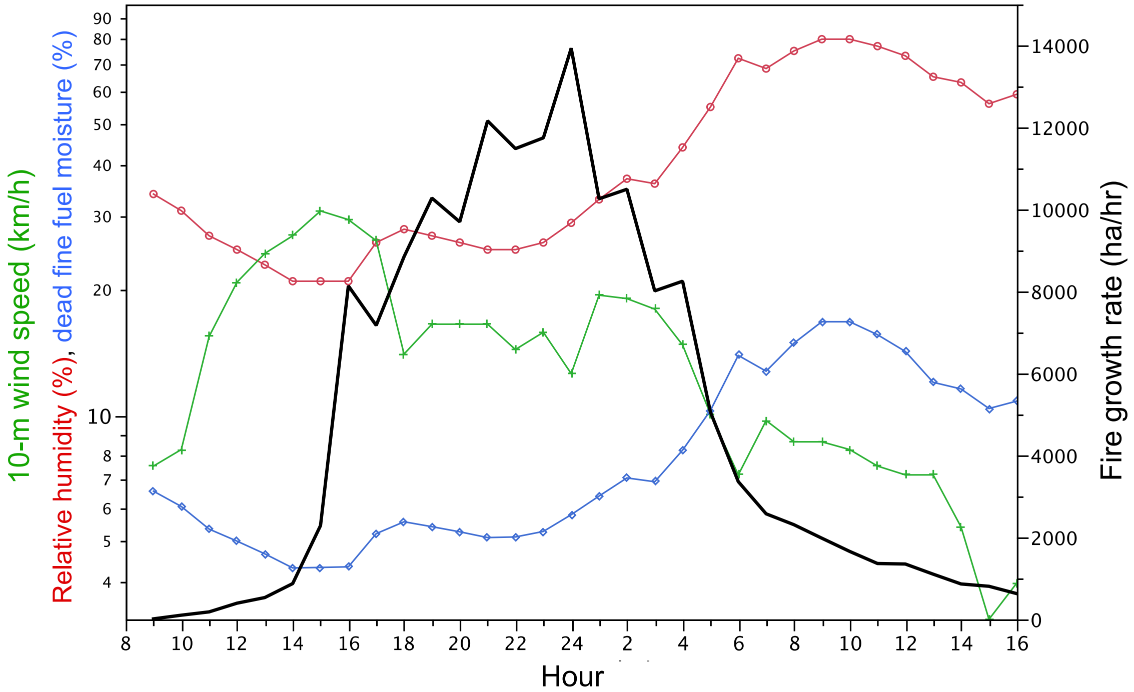


***Figure 1 - Combined fire growth rate of the studied fires and fire weather elements at Viseu from 9:00 of October 15 to 16:00 of October 16, 2016. The Viseu weather station was selected because it simultaneously reflects the Ophelia effect on wind speed and the downdraft after midnight.***

Looking at FLI fire by fire we found two types of fire spread patterns on the afternoon-evening of the 15th of October. On the coastal region, fires were of the 'wind driven' type at their peak in the afternoon, in contrast with the inland fires, which were 'plume dominated' (Rothermel, 1991) when they made their major growth late on the 15$^{th}$ or early in the 16$^{th}$. Figure 2 shows the pattern of coastal fires. Wind driven fires peaked around 16:00 to decline sharply after 19:00 with the slowing down of wind and the increase in relative humidity, displaying the expected pattern. The inland Lousã fire in Figure 3 shows a totally different pattern. It also peaks initially around 16:00 with the wind, but it is under weaker wind and increasing relative humidity that its higher FLI and subsequent growth peak occur. This corresponds to a plume dominated fire and a transition from PyroCu to PyroCb and the subsequent and associated downdraft phenomenon that allows the generation of firestorm-type fires that dramatically increase the burned surface (Fromm et al 2010).

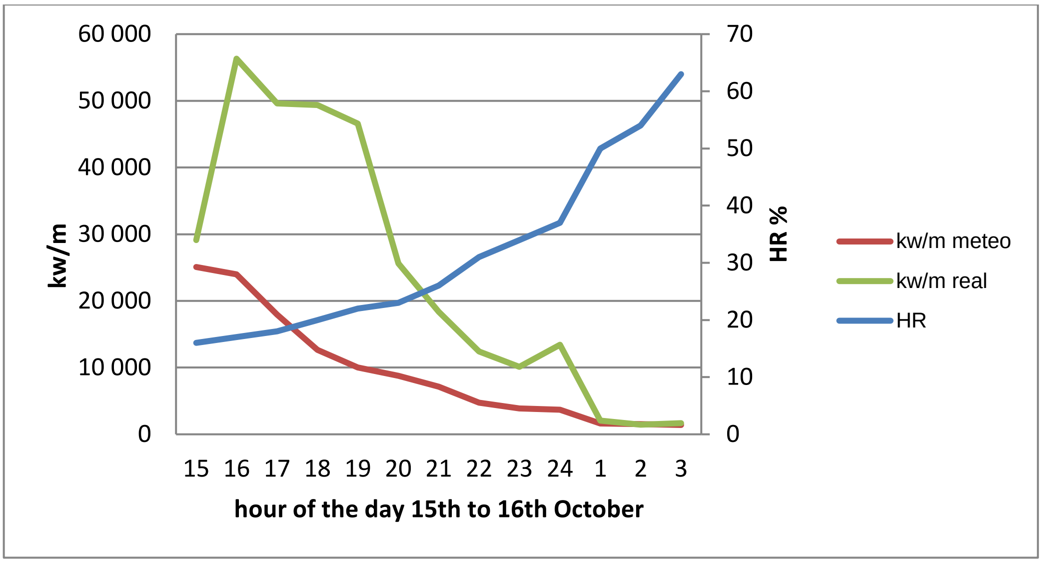


***Figure 2 - Relation between reconstructed and simulated FLI for the coastal fire of Quiaios. HR is the air relative humidity.***

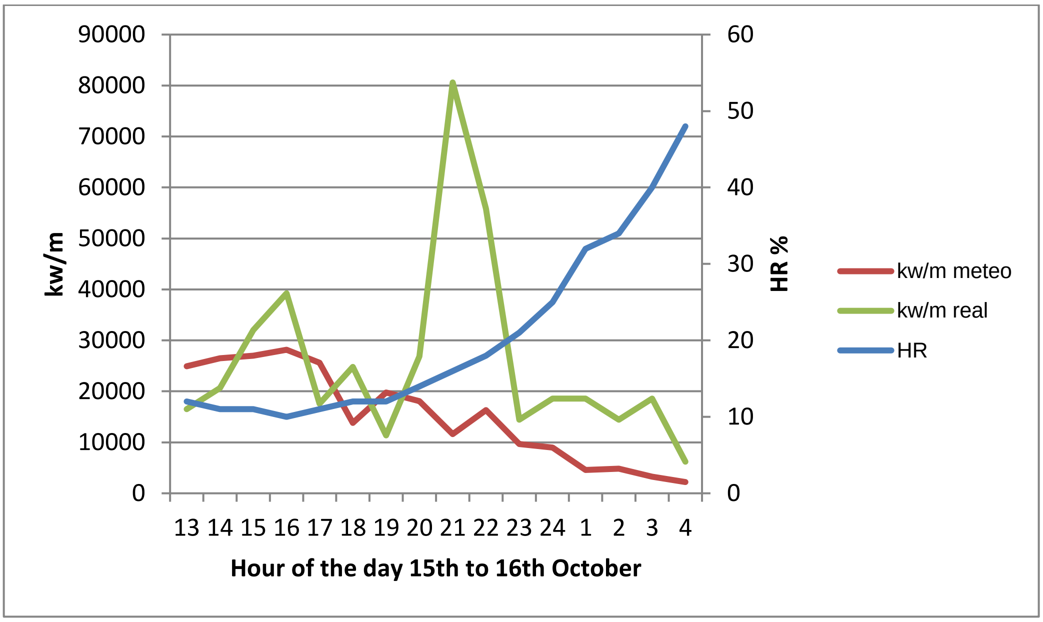


***Figure 3 - Relation between reconstruted and simulated FLI for the inland fire of Lousã. HR is the air relative humidity.***

## 4. Discussion

The burning afternoon and evening of the 15th of October 2017 was driven by different factors which combined to create what is seen in Figure 1, favouring different types of spread at each moment and increasing because that unpredictability among population and fire service. That huge amount of surface burned was achieved by a chronology of events that included the hurricane-like storm Ophelia first and weaker winds with higher instability later. This created the already explained different types of fire behaviour, but it is the piling-up and especially the large and interacting land surfaces on fire that produced the huge difference. This is described in Table 1 and explains how the wind first expanded long narrow fires and then a series of transitions of PyroCu to PyroCb created indraft and downdraft events to expand those fires with gale strong winds and erratic movements mainly on the axis from SW to NE. In fact, what was seen in Pedrogão Grande in June was repeated here after Ophelia's passage for three large fires and was sustained from 19:00 on the 15$^{th}$ to 04:00 on the 16$^{th}$.

***Table 1 Description of the moments of fire behaviour found when reconstructing the fire events.***

| **Hour** | | **Coastal** | **Inland** |
|---|---|---|---|
| **11:00 to 14:00** | **Wind Driven** | | Wind driven fires |
| **14:00 to 15:00** | | Narrow long wind driven fires<br>Fires in Quiaios and Pataias show Pw>Pf and sometimes Pw=Pf. | Arganil and Lousã fires are shadowed by Sertã fire where instability increases. They start to show the first PyroCb. They create a huge indraft that 'attracts' Sertã to them. Sertã has Pw>Pf due to that. |
| **16:00 to 19:00** | **Wind slows down and fist wave of** | Wind is slowing down and Pw keeps close to Pf. PyroCu development but still not evolving to PyroCb, peaking at 5000-6000 m. Long distance spotting. | Wind is slowing down and Pw keeps close but is slightly lower than Pf. We have PyroCu going on that still not evolves to PyroCb, peaking at 5000-6000 m. Long distance spotting. |
| **19:00 to 23:00** | **Second wave of PyroCb with RH increase** | PyroCu are huge and spotting distance increases. Low jet is disappearing and this avoids transition to PyroCb. High dispersion of PyroCu. With RH increasing fires remain wind driven and start slowing down but they are already extremely large<br>The south fire is creating a small transition to PyroCb when the first humidity comes in. The northern convection plume, shadowed by the south plume is not registering this moment. | Increase of humidity allows PyroCu transition to PyroCb and Pf doubles Pw. Big indrafts and fire to fire interactions are generated. Huge fire storm builds up its momentum.<br><br>From 19:00 to 23:00 the three fires have huge pyro convective activity. This is a feedback of sequential and sustained PyroCb outflows. |
| **00:00 to 04:00** | **Front arrival and inland final collapse** | Wind driven fires. RH is high and FLI relatively low. Fire spread is totally impelled by the Pw | The Lousã PyroCb, the last and northernmost one, collapses and drives all fires to NE. It has been the longer lasting fire of the event. This downdraft changes the nearby Arganil fire into a wind driven fire with Pw>>Pf, just when the general wind is at its lowest. |

It is important to note that the wind created long and fast-growing fires with substantial pyroconvective activity that favoured long distance spotting. This pyroconvective wind driven activity dominated fires in the first two stages. Under those wind driven plumes, higher instability could appear and that pushed convection columns higher and higher, creating huge PyroCu than then were rolling down, spreading and spotting away. Those typical and well know columns induced fast fire growth due to long distance and massive spotting, as observed during those moments in central coastal and inland Portugal.

Later, with Ophelia fading away and instability increasing while wind was calming, and relative humidity was increasing, it is when third stage appears. Fires on the coast were huge and unstoppable but they were starting their decline, unlike inland. Here, fires were able to access free convection in their atmosphere, so they transitioned into PyroCb, increasing indraft and downdraft or outflows that kept pushing the fires further away. Out of those fires, Sertã was being pushed by the indraft of Lousã.

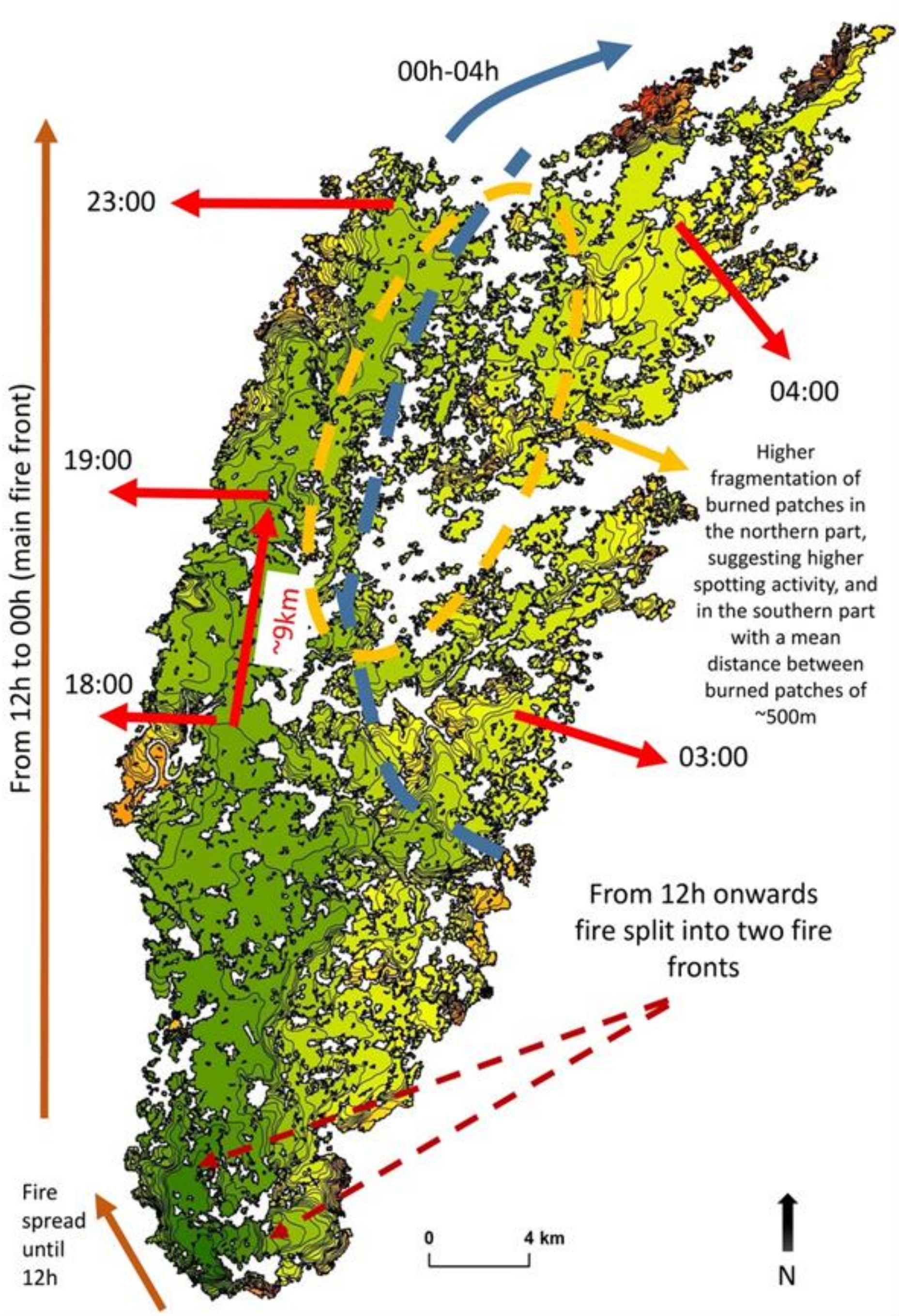


***Figure 4 - Spread of the Vilarinho (Lousã) fire. Note the growth after 00:00 (blue line) into patchy fuels. This was possible because at that moment the outflows of pyroCb collapse were pushing the spread opening to the ENE.***

Finally, the last moment developed about midnight, when the largest PyroCb (Lousã) collapsed, expanding itself and then ending the event. Those events of interacting outflow and indraft from different moments and the collapse of PyroCb can explain the high percolation of those fires in areas with low fuel connectivity (Figure 4).

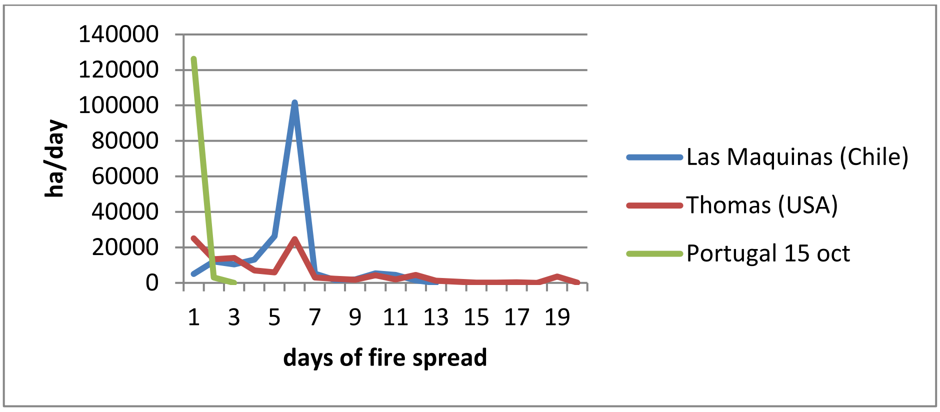


***Figure 5 - Daily growth rate for three of the largest fires globally during 2017.***

## 5. Conclusion

Some have argued that we are not facing new fire management challenges and that those were already present in other places. In Figure 5 we can see how Portugal's fires rate as the fastest growing among the largest of the 2017's season globally. This is really bad news for Europe, as our unmanaged landscapes are becoming a threat.

What we saw in Portugal during 2017 is a change on Europe's fire behaviour concept in terms of rate of spread, FLI and fire growth rate. Out of the large fires described, the second type, which matches the so-called 'plume dominated wildfire' is the most dangerous for European citizens and countries due to its unpredictability in terms of when the event will occur and where it will go. This is not new in terms of the phenomenon and had been seen in 2003 in Portugal, 2007 in Greece, and 2012 in Spain on a substantially smaller scale. Having those events in an overcrowded country implies pressure upon the forest firefighting culture to change to a civil protection approach. It is not anymore a matter of forest and landscape; it is a matter of national security and civil protection. It is within this view that forest management resources need to be fostered to protect our society and economy.

Given the observed fire behaviour and how it developed, the Atlantic facade and western central Europe are under pressure for those types of fires and phenomenon. It means the characteristic high net primary production turns into extreme fuel availability due to heat and drought extremes and this is the type of fire behaviour, with PyroCu to PyroCb transition, that is expected under the new fuel aridity that climate change is bringing in. For years to come, the approach to forest management and firefighting must change and be perceived from this new perspective. Landscape management rather than fuel management is needed to impact fire spread at such a large scale. Most importantly is that other countries will have conditions to reproduce such fire behaviour but will be inexperienced at this new reality. More than ever, no time should be wasted in thinking that fire suppression will 'make it' and a valuable lesson has been learnt and should be disseminated.

## 6. References

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