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Recent Forest Fire Related Accidents in Europe

Domingos Xavier Viegas (Editor)

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Cover page: Fire spread during an experimental fire in Gestosa (Portugal) 9 May 2009
Photo by CEIF/ADAI

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Preface

Forest fires or wildfires are an integral component of Mediterranean ecosystems in Europe and around the world. However the way in which humans deal with wildfires has rapidly changed throughout the years, especially in Mediterranean Europe. European Mediterranean ecosystems are characterized by several conditions. These include the rural exodus to cities leading to the abandonment of forests of low timber production, and the simultaneous accumulation of fuels in these forests. Additionally, as living standards in Europe have evolved, rural areas have been populated by secondary homes, which have enlarged the wildland urban interface. Human populations and assets are thus at a higher risk of forest fires than ever.

Fire trends in Europe show a high concentration of fire events and, more importantly, fire effects in the Mediterranean regions. About 80% of the total burnt area in Europe concentrates in this Region. Although the number of fires seems to be decreasing in the last decade, critical weather conditions have recently caused unprecedented damages in economic terms and in number of human casualties. This book comes in a very adequate moment in which society, national and European governments are discussing potential options under future climate change conditions that may trigger more dangerous and more frequent forest fires. The loss of human lives is the worst outcome of forest fires and this has repeatedly occurred in the last years. The number of lives lost of civilians and forest firefighting crews has increased in the last decade. This book analyzes some of the major accidents that lead to these accidents. This analysis may lead to an improved fire risk management and to a more efficient and safer control of forest fires. The book provides an essential complement to data recording and analysis in the context of the European Forest Fire Information System (EFFIS) and provides a human component that is not covered in the system. I would therefore like to thank Dr. Viegas for the initiative of editing this book and publishing it under the umbrella of EFFIS.

Jesus San Miguel Ayanz

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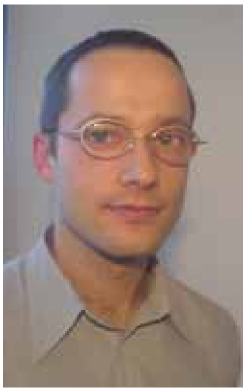

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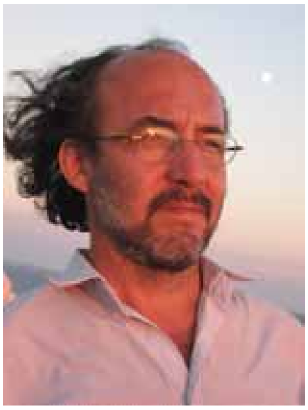	**Darko Stipanicev** Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture,University of Split Split - Croatia *Email: dstip@fesb.hr*
	Darko Stipaničev is Professor of Computer Science and Automatic Control at Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture University of Split and head of Department for Modeling and Intelligent Systems. His research interest include complex systems modeling and control, intelligent systems analyses and design, digital image processing, analyses and understanding, advanced Internet technologies and recently, the application of information and communication technologies (ICT) in various forest fire activities, particularly software support to forest fire prevention and management. More details on http://laris.fesb.hr/dstip-e.html.

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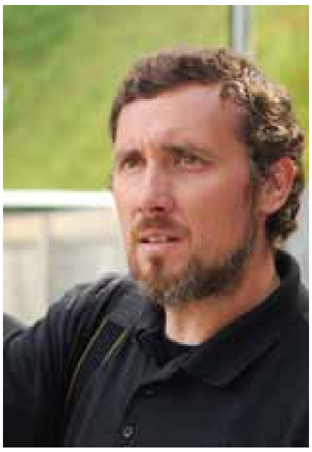

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1. Introduction

Domingos Viegas

Forest fires are commonly recognized as a threat to Nature and to the Environment and most often their direct effects are quantified in terms of number of fires, of burned area, burned houses or economic losses. In our opinion it is strange that the effects of forest fires on human beings, even when there is loss of lives are rarely mentioned in the official or technical reports. This attitude is also reflected in the scientific research in Europe that has paid very little attention to the problem of fire safety in the context of forest fires. There should be a change in this attitude as human life is by far the most important asset that may be in danger during a forest fire.

Nowadays it is very common to speak about the co-called urban-wildland interface (UWI). A colleague of mine, Luis Mário Ribeiro, in a personal communication some weeks ago introduced me a very interesting and original concept, that of Human-wildland interface (HUI). This is surely the ultimate barrier that has to be guarded with the maximum priority, as persons are certainly more important than houses.

Forest fires provide ample field to put human life in danger. Practically all fire management related activities involve some risk. Strictly speaking fire entrapment is the major threat that forest fires pose. An entrapment is usually the result of an interaction between human behaviour and fire behaviour both of which require our attention and better understanding.

Research on fire related accidents is a common place in other regions of the World, namely in the United States, in Canada and in Australia. The lessons learned in those countries have helped to develop training methods and operational rules that are now applied almost universally. In Europe we also need to develop and improve our fire safety culture based on our own cases and facts. This is not only a way to prevent the loss of lives directly through a better training of fire management and fire suppression agents but also indirectly inducing more awareness in the general population to avoid behaviour of risk.

Unfortunately the loss of lives in fire related accidents that have occurred in European countries during the past years cannot be ignored. In Table 1 we show the numbers that were made available to us of fire losses in each country during the past twenty five years.

Table 1. Number of fatal victims in forest fires related accidents in some European Countries

Country	Period	Number of victims	Remarks
Portugal	1982-2007	110	Includes the 21 victims of 2003 and 22 victims of 2005.
Spain	1982-2005	186	
France	1982-2007	20	
Croatia	1980-2007	28	Includes 8 firefighters that were killed while fighting forest fires during the War.
Greece	1980-2007	177	Includes 78 victims in the year of 2007.

The numbers given above although impressive are not so important, as our goal should be to have not a single life lost due to fire related actions.

We have all in mind the tragedy that was unfold in Greece during the Summer of 2007 in which 78 persons were killed due to the forest fires. This fact alone should promote a general reaction in Europe of having more attention towards this subject.

The present author was motivated to initiate his research activity in the field of forest fires by an accident that occurred in Portugal in 1985 in which 16 firefighters of Armamar lost their lives when fighting a forest fire near their city. Since then he has investigated practically all fatal accidents that occurred in Portugal with the purpose of understanding better the causes of these accidents and of finding ways to avoid them. This objective has guided his research in fire behaviour and in particular that most related to this type of accidents.

During the last years some important accidents with multiple fatalities have attracted the attention of the authorities but also of the scientific community. In a meeting that was held in London by initiative of Dr. A. Simeoni, with the support of the French Embassy in London with the purpose of creating a network dedicated to study the eruptive fire behaviour that is associated to the majority of these fatalities the proposal of publishing a volume of the EUR Scientific and Technical Research series dedicated to the topic of fire safety was raised. I accepted gladly the honour to coordinate this volume that includes the analysis of some of those accidents.

I wish to thank all the authors of the chapters of this book for their valuable contribution to it, through their research and study of each case.

We hope that this book may be helpful to all those interested in studying forest fire related problems and in particular to those that have to deal with fire to manage it with the risk of their lives, with the hope that they may perform it more safely in the future.

2. The Accident of Guadalajara (Spain) 2005

Domingos Viegas and David Caballero

This accident occurred during the fire suppression operations on the second day of a very large fire in the Province of Guadalajara, Spain, and it caused eleven fatal victims and a badly injured survivor, all of them firefighters. This fire lasted for four days and burned an area of more than 12,000 ha.

The authors visited the site of the accident few days after and produced a report of the accident that was presented to the authorities (Viegas *et al.,* 2005). This fire had a tremendous social and political impact in Spain, as well as ecological and economical consequences in the affected region, and still, at press-time, the echoes of such disaster have had effect in the policies of forest fire prevention and fighting.

This fire was started inadvertently on the 16th July 2005 by a group of excursionists that were visiting the protected area of Alto Tajo Park, a picturesque site in Valley of Milagros with a cave and a natural monument, near the village of Riba de Saelices. After visiting the Cueva de los Casares cave, with pre-historical traces and very frequented by people, the group decided to prepare a barbecue against the advice of the local guide, given the hot weather and strong wind situation on that day. Although the barbecue was being prepared at a stone-made picnic site, the fire was momentarily unattended by the excursionists. In a very short time the fire produced enough embers that ignited a nearby field of stubble, see Figure 2.1. Driven by the strong wind, the fire spread very quickly in the extremely dry vegetation rendering fruitless the efforts of the group to extinguish it by the time they realized there was a fire catching up. Alarm was given in the following minutes as the fire went across the stubble field, jumping into the neighbouring slope with cured grass and shrubs, and then entering in an area of complex topography covered by a large extension of old *Pinus pinaster* plantations and shrubs that were very dry due to an extended drought that was felt in the region and in the Iberian peninsula during 2005. At this stage, and in around one hour time lapse, the fire became virtually uncontrollable.

Figure 2.1. Aerial view of the location of fire origin near Riba de Saelices. The barbecue site and the stubble field can be clearly seen in this picture. Initial fire progression was from right to left in this photo.

After the initial consolidation, fire developed very quickly in the first two hours pushed by the strong winds. By the time the head was reaching a cultivation area in the town of Ciruelos, an attempt of stopping it was successfully performed, leaving two very intense flanks in their way to other population areas in the zone. The right flank progressed towards Selas, jumping fuel breaks without control; the left flank was advancing in a complex terrain towards Santa María del Espino, creating difficult situations and giving no chance for its control.

On the 17th the left flank of the fire was spreading in Valley of Milagros and was endangering the village of Santa Maria del Espino among other villages in the area. By that time a general command was broadcasted to all ground and air crews, of holding any attempt of direct attack to any of the fronts, particularly the left front in Santa María del Espino which was developing noticeably, and instead to provide support and defense to the populated areas, basically rural towns, in the case of an approaching fire threat. Following this command, a task force was assembled at Santa María del Espino to prepare the defense of the village. Pedro Almansilla, the leader of this task force, decided to attempt to control the fire advance on the ridge above the Valley of Milagros while it was still far from the village, and in an area mostly dominated by shrubland in the fringe of a pine stand. At about 16.30h he led a group of twelve fire fighters travelling in five vehicles along a forest road to attack the flank of the fire on the ridge, which by that time was progressing in the pine stand.

The group included P. Almansilla who drove an all terrain vehicle V1, the boss of the fire crew who drove a similar vehicle V2 and a crew of seven fire fighters who travelled in another all-terrain vehicle V3. Two fire tanks V4 and V5 that had a crew of two and one person each respectively completed the task force. Approximately at 17.10 h they parked their vehicles at the border of the pine stand and started to deploy hoses of both fire trucks and attack the fire on both sides of the forest road.

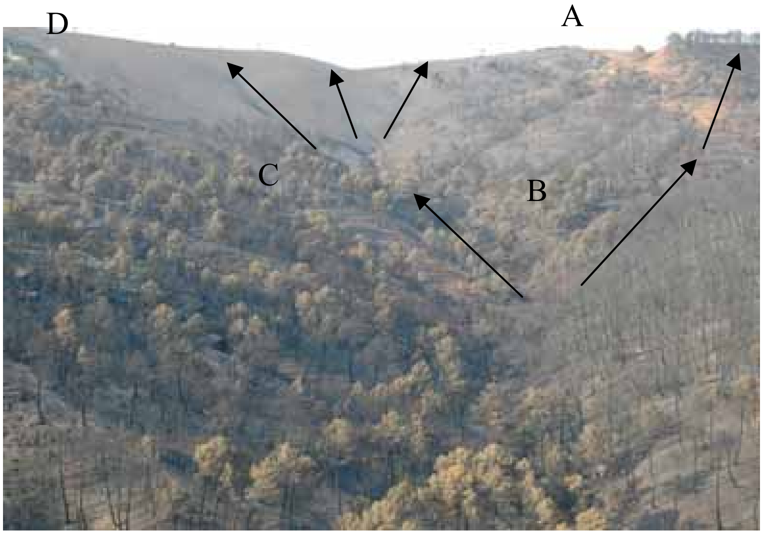

Figure 2.2. General view of the valley and the South slope in the area of the accident. The group was fighting the fire in a pine stand on the right side of the ridge (A) when the fire erupted in the pine stand on the right hand slope (B). The group was caught while travelling on the road towards the left side by a second eruption on the left side slope on shrubland (C). The silhouette of V1 can be seen on the horizon (D). The arrows show the progression of both eruptions from the bottom of the valley.

Unknown to them, around 17.15 h a fire started in a pine stand on the South-facing slope, below them and at their right side (see Figure 2.2.). Most probably this fire was caused by very active spotting produced in the flank near the bottom of the valley and below the road. Given the poor visibility from the ridge of the bottom of the valley, due to the terrain convex configuration, it is probable that the crew didn't perceive that an incipient fire was starting in such position below them. Unfortunately at that time there was no other ground or airborne observers that could have warned the group with greater advance of this potential danger. In a matter of minutes, this spot fire entailed a first fire eruption on the pine stand with a very intense crown fire that certainly created a great concern to the group due to the speed and violence of development. Assuming that the control of the fire at that section was lost, and to avoid an imminent entrapment by this intense fire front, they decided to run away from such position as soon as possible towards the shrub zone, where presumably the fire intensity and speed should be much lower, using as escape route the same way they had used for entering the ridge less than thirty minutes before.

In order to proceed with a faster escape from the menacing fire, the group decided to leave the heavy 10-ton fire truck V4 behind, while its two crew members boarded vehicle V2. The decision of abandoning the fire truck provides an indication of the alarm degree created in the group by the advancing fire. P. Almansilla led the escape in V1 followed by V2 a little behind and V3 shortly afterwards. We now know that if they had managed to drive for about 1.5 km along the road they could have reached a safe place. Unfortunately for them in the few minutes that took the group to get into their cars and after driving for a distance of less than 400m, a second eruption took place below them in a sort of canyon. This eruption progressed very rapidly in the slope covered by shrub vegetation, heading towards and hitting the escape route of the moving group (see Figure 2.2.).

In few seconds the ridge was full of smoke and very hot air, and probably because of this the engine of V1 stopped. Then P. Almansilla left his car and with difficulties of breathing and his visibility greatly impaired by the thick smoke, he managed to walk for some meters away from his car before being doomed by the raging fire. The same happened to V2 and its three occupants, that were driving 100 meters behind V1, see Figure 2.3.

The driver of V3, perceiving the approaching column of smoke and fire ahead across the road, decided quickly to follow an alternative escape route, first turning right off the road into an unburned area of shrubs and rocks, and then turning left driving parallel to the road at a distance of it and in the other side of the ridge. Under such dense smoke the visibility was null, and the driver was progressing blindly until he smashed the vehicle against a wall of loose stones. The vehicle was badly damaged and trapped among stones. Five of its seven occupants made a desperate attempt to run away and shelter them against the wall, while the other two remained inside the car. Finally, the hot air and flames reached their position killing them all. The accident occurred at about 17.25 h.

At the same time, J. Abad, the driver of V5, was much behind, as he was delayed in his escape process, perhaps because he was busy handling the hoses and the water pump of the truck. This fact saved his life. When he boarded his truck he was alone and the thick smoke had already invaded the area. Driving with very poor visibility and under high strain, he soon noticed that the vehicle was slipping off the road towards a deep ravine. Unable to stop and having lost control of the vehicle, J. Abad decided to jump from it through the opposite window, falling on the ground and badly injuring himself, but managing to crawl in the direction of V4 and shelter below it. Fortunately for him there was practically no vegetation in that spot so the fire didn't' reach his position. Besides he managed to open one of the water outlets of the large tanker, letting water freely flow onto him and thus providing some relief to the intense heat that was blazing around. From his position J. Abad could hear the cries from the other crew members, as he saw the huge flames coming upwards towards them "like two giant arms that came looking after them", as he later declared. Although he suffered serious injuries and some burnings in head and hands, he managed to survive the dramatic event.

Figure 2.3. View of the three vehicles that participated in the escape attempt of the group. Vehicle V1 is in the foreground. Vehicle V3 can be seen on the left side of the photo near the stone wall. The arrows show the direction of eruptive fire progression.

A study performed by Rossa *et al.* (2006) including a simulation of the incipient fire in the laboratory, showed that the rate of spread of the fire in herbaceous vegetation similar to the stubble that existed near the origin of the fire was of the order of 2.0 km/h. Embers carried by wind would contribute to make the suppression of this fire front using hand tools by a limited number of persons impossible.

According to the detailed analysis of the fire behaviour in the event, which was performed by ADAI and synthesized in a technical report realized for the judicial investigation, an unexpected and fast-growing development of the fire speed and intensity was the ultimate cause of the accident and the fatalities, in a phenomenon commonly addressed as blow-up or eruptive fire. This eruptive behaviour that occurred during this accident is characteristic of canyons as was described in Viegas and Pita (2004) and in

Viegas (2005). In order to reconstruct the fire behaviour in the canyon prior to the accident, several tests were made at the Fire Laboratory of ADAI in Lousã. The large canyon Table DE4 was used for this purpose setting its faces with the actual angles of the slopes and water line, see Figure 2.4. A point ignition was made at a position equivalent to the base of the pine stand where the ember landed. An initial eruption on the South facing slope (right hand side of the picture) was observed. Afterwards, when the fire reached the correspondent water line and entered the left side slope, a very fast eruption on that slope started, just in the point below the corresponding position of the group. These tests were performed in absence of wind, and confirm the likelihood of the existence of the double eruption phenomena induced by the fire in the canyon, as proposed by the authors, to explain the sudden and fatal fire behaviour change during this accident.

Figure 2.4. Experimental simulation of fire spread during the Guadalajara accident at the large Canyon Table DE4 of the Fire Laboratory of ADAI.

We now know that if the group of fire fighters had remained in the same area where they were they could have survived given the fact that there was not much vegetation in a wide area around the road at the place where the vehicles were parked. The fact that J. Abad survived at this site without much protection supports this assertion. If they had entered the cabin of the heavy fire truck or if they had the possibility of using fire shelters their chances of survival would be greatly enhanced. The decision of the group to run away is quite understandable because a wave of very intense fire was unexpectedly coming towards them from what was previously a flank and the identified escape route was very clear, apparently safe and practicable for them.

This accident aroused great controversy in the public opinion in Spain, first of all because of the victims, but also because of the apparent lack of fire prevention measures and the circumstances of fire suppression management and coordination and the mis-observation of safety rules. In fact, these were quickly pointed out as the possible causes, or at least drivers, of the accident, despite of the fact that P. Almansilla had long experience and knowledge about fire fighting and the terrain in which they were operating. In this sense, in the opinion of the present authors, it is very difficult to blame anyone for an accident under the mentioned circumstances, given the need first to recognize the indicators of potential danger of eruptive fires and fatal entrapment by observing the local terrain configuration, a task which can be done more appropriately by the personnel present in the terrain. In our opinion a better training of fire fighters, incorporating the findings of scientific research and the lessons learned from past accidents such as this, is the best way to be prepared to face these situations and to avoid future disasters.

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3. Accident of Famalicão da Serra (Portugal) 2006

Domingos Viegas, Luis Pita, Carlos Rossa and Luis Ribeiro

Introduction

In this accident six fire fighters lost their lives while attempting to suppress a large fire in the outskirts of the small village of Famalicão da Serra in the District of Guarda in the Centre of Portugal in the early afternoon of the 9^{th} July 2006. Five of them were Chilean citizens that worked in Portugal as professional fire fighters for Afocelca, a private company especially dedicated to protect tree plantations belonging to a group of Portuguese cellulose plant companies. The sixth victim was a Portuguese volunteer fire fighter of the local fire brigade of Gonçalo that was working with this team.

This accident had a great impact not only due to the number of victims and the circumstances of the accident but also because a whole team of foreign professional fire fighters had perished due to fire.

The first author was designated as a member of the official Committee to investigate this accident.

Description of the accident

Ambient conditions

The fire developed in a slope of Serra da Estrela overlooking a valley in which the small village of Famalicão is situated. The initial part of the slope was covered by agricultural land with some herbaceous and other light fuel vegetation; the upper part was covered by a mature pine stand that was clean and protected by a wide fire break.

Fire weather conditions were extreme in that day, with temperatures of the order of 35ºC and relative humidity of the order of 15% with light wind blowing from East-Southeast, as can be seen in the data from the meteorological station of Meimoa. (Figures 3.1 and 3.2)

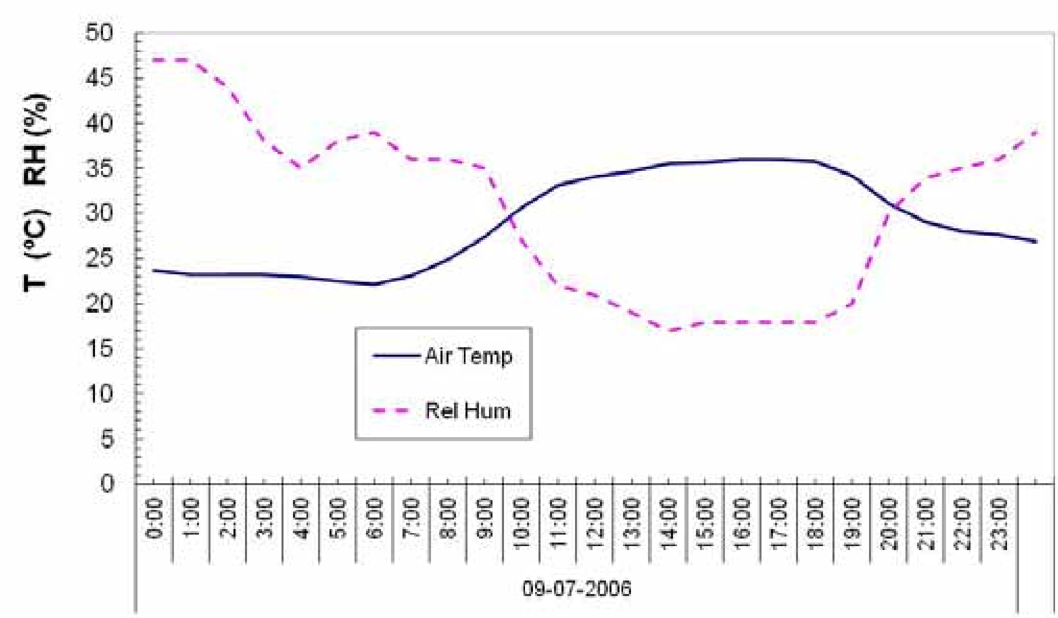

Figure 3.1. Air temperature and relative humidity during the day of the accident at the nearby station of Meimoa.

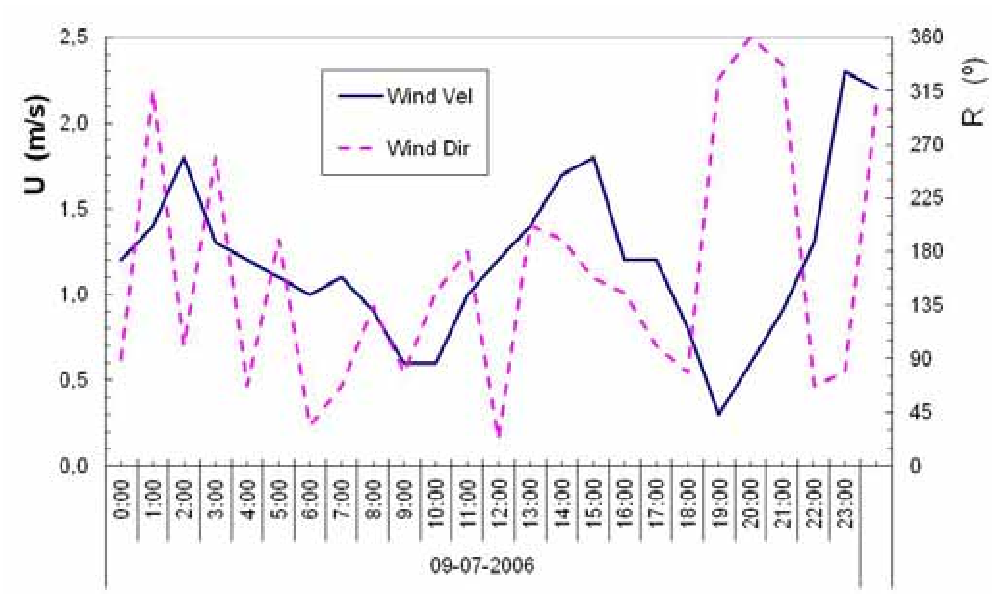

Figure 3.2. Wind velocity and wind direction during the day of the accident at the nearby station of Meimoa.

Figure 3.3. General view of the area of the fire of Famalicão. The origin of the fire was near the bottom centre of the picture. The accident occurred in the canyon at the centre of the photo.

Fire origin and initial attack

The fire was started by accident at 12.30h in a farm due to sparks released by the blades of an herbaceous cutting machine when they touched some stones. In spite of the fact that there were two persons in the area that tried to suppress the initiating fire using a car fire extinguisher, their efforts were not successful and the fire spread quickly through the farm and entered the slope.

A light vehicle of the local section of Volunteer Firefighters of Gonçalo was immediately dispatched and reached a rural road above the location of the fire origin. The fire extension overwhelmed their capacity and crossed that road. Helped by the slope and the wind the fire spread in the direction of the top of the mountain. This group left the place and headed for the top where another group of firefighters and several other forest owners and civilians were already working trying to protect the pine stand.

The alarm was given and among other means two heli brigades were dispatched to the fire. One of them was of the National Civil Protection and landed near the base of the fire at its right flank. Due to the ruggedness of the terrain in that area and the large quantity of fuel the suppression of that flank was not achieved entirely. With the arrival of more fire trucks this team left the area practically when the accident happened.

The other heli-transported brigade was that of Afocelca and was composed by five Chilean fire fighters. They landed on a road near the top of the slope in the border of the pine stand that they we required to protect.

The fire had already entered the pine stand as a flank fire backing against the wind and had burned the triangle that can be seen in Figure 3.3, formed by the two fire breaks and the row of burned pines.

The team started to work with hand tools in a line down from the road along the row of burned pines and to its left. A fire fighter of the local Brigade of Gonçalo was ordered by his Commander to help the team of Chilean fire fighters to suppress the fire. Their position seemed to be safe and the group was advancing quickly down slope extinguishing the relatively short flames produced by pine litter that were spreading against wind.

Fire entrapment

After some minutes, at around 13.30h there was a sudden sequence of fire eruptions below the position of the group and the fire started to burn the crowns forming three strips that can be seen in Figure 3.3. There was a general alarm. Those that were placed above near the road escaped along the top of the ridge to the right side. There were spot fires and some persons suffered slight burns in their escape.

The group of six fire fighters that were at mid slope decided to run away from the crown fire to the left side of the main fire. They went basically along the road towards the centre of the large canyon in which they were.

Unknown to them the bottom of the fire was not being suppressed on the ground due to the difficulty of access. Only one helicopter was dropping water in the left flank of the fire near its bottom without support from the ground.

While the group was running away from the main fire the left flank entered the water line and the slope on the right side of the canyon. In few minutes the fire erupted along that slope cutting the escape route of the group. When the road reaches the water line there is an open area without vegetation. There the group split in two. The Portuguese fire fighter decided to stay in the same area ant took cover in a trench at the edge of the fire break.

The five Chilean dropped the material that they still carried with them and following the command of their boss departed uphill trying to escape to the two walls of fire that were approaching them. The terrain in that direction is quite rough with terraces with barriers of four to five meters. One of the fire fighters was able to climb four of them and reach a distance of 60 meter from the starting point.

The very strong convection induced by the erupting fire in the left slope forced the fire in the pine stand to converge over the group that was completely overwhelmed by smoke and fire.

The body of the Portuguese fire fighter was found unburned due to the sheltering effect of the stone trench in which he took refuge. The five Chilean fire fighters also died in the middle of the pine stand. Some of them had attempted to use a respiratory device but to no avail.

Fire Simulation

There was a general belief that the cause of the entrapment was a sudden change of wind direction. There was no evidence of this in the wind records.

A simulation of the fire in the Famalicão canyon was made in the Large Canyon Table DE4 of the Fire Research Laboratory (LEIF) of the University of Coimbra in Lousã. The basic canyon geometry was reproduced and straw was used as fuel bed. A line fire was ignited to simulate the position of the left flank of the main fire when the Chilean Brigade moved in. The fire spread slowly widening its flanks until it reached the water line. When this happened it erupted and burned the left side of the canyon in few seconds.

This simulation showed that the fire induced convection had produced the sudden change in behaviour that was interpreted as caused by a wind shift. A sequence of images of one of the tests that were performed is shown in Figures 3.4 and 3.5. Notice that the time step between frames changes from 20 seconds in Figure 3.4 to 6 seconds in Figure 3.5. The dramatic acceleration of the fire when it enters the left side slope of the canyon can be clearly perceived in this sequence. There were no wind effects inside the Laboratory during the experiment.

Figure 3.4. Sequence of images of fire spread during the first 100 seconds of the test performed at the DE4 of LEIF. The time step between frames is 20 seconds.

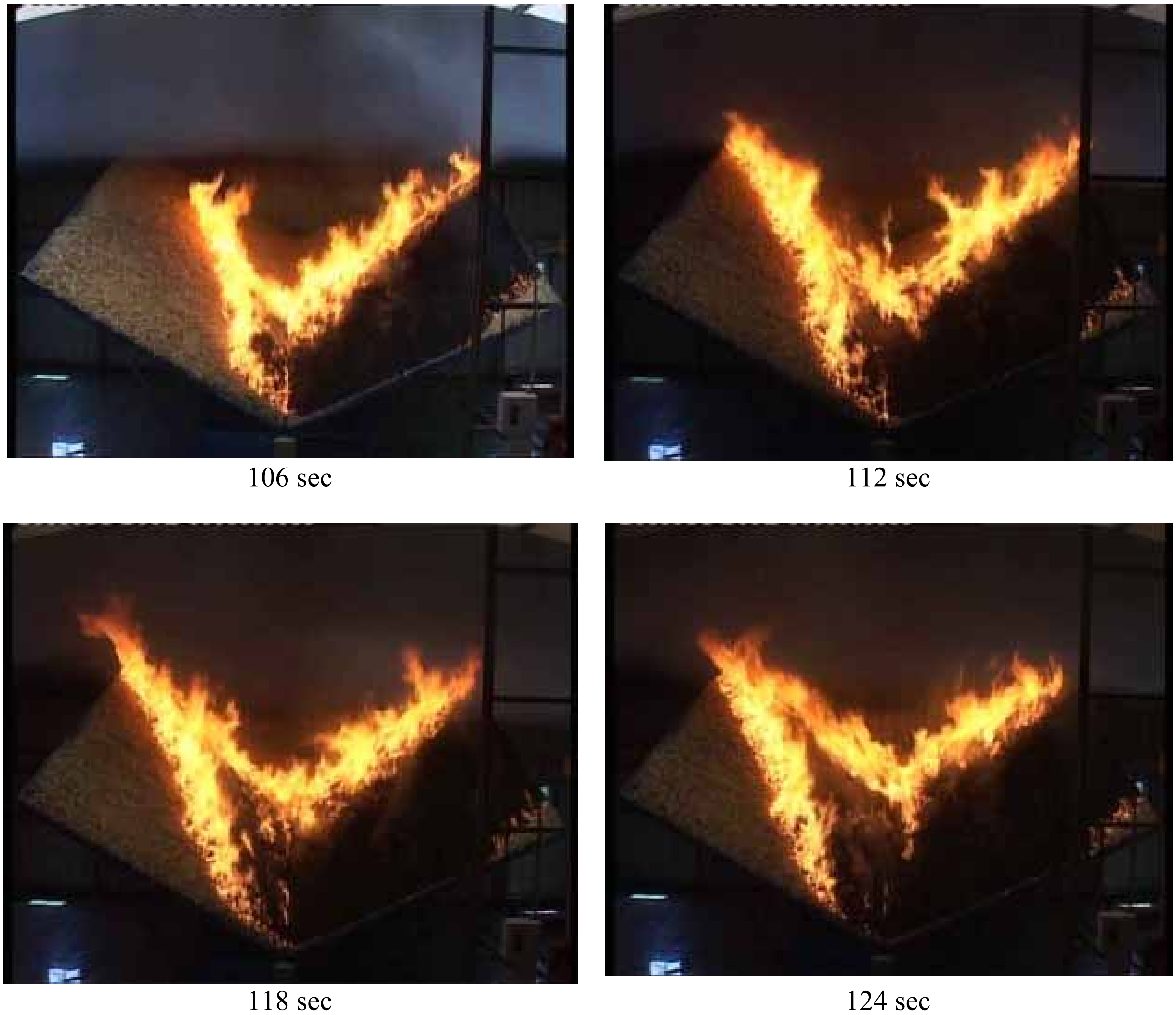

Figure 3.5. Sequence of images of fire spread during the following 24 seconds of the test performed at the DE4 of LEIF. The time step between frames is now 6 seconds.

Conclusions

The present case study involved the loss of six fire fighters that were entrapped by a fire erupting in a canyon. What was apparently a safe situation and almost routine fire suppression turned out to become a death trap. It is arguable that the use of fire shelters might have saved the lives of these men, but it cannot be said as sure.

The simulation of the accident that was performed in the Fire Laboratory produced convincing results of fire behaviour during the entrapment. It showed in particular that no wind shift was required to explain the sudden acceleration of the fire on the left side of the canyon that caught the group of six fire fighters by surprise.

Acknowledgments

A word of thanks is given to the Meteorological Service and to the National Authority of Civil Protection for the data provided and for the support given.

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4. The Accident of Kornati (Croatia) 2007

Darko Stipanicev, Domingos Viegas

Preamble

Croatia belongs to the group of European countries with high forest fire risk that have many rural and forest fires, particularly in summertime, along the coast and on the numerous Croatian islands. Damages caused by fires are not very high because the fire fighting service in Croatia is quite well organized, having both professional and voluntary fire fighting organizations. The history of organized fire fighting in Croatia is 144 years old and during this long history, until 2007, not a single fire fighting accident with a large number of causalities had been recorded. Since 1980 not more than 15 fire fighters and civilians have lost their lives as a direct consequence of forest fires. The accident of Kornati that happened on August 30, 2007 is therefore the largest fire fighting accident ever recorded in Croatia. Twelve fire fighters, both professional and voluntary, lost their lives and one was badly injured in a small canyon near Sipnate bay on Kornat Island in Kornati National park.

In order to explain what had happened in Sipnate canyon and why experienced fire fighters lost their life during an apparently quite simple intervention, the Office for National Security of Croatian Parliament and law-court in Sibenik have engaged more than 50 researchers and experts from various fields. One year after the accident a report with the main results of this investigation which emphasis is on physical aspect of the accident, primarily meteorology, vegetation, fire spread, aerodynamics and thermodynamics was reported.

Our aim in studying this accident was not to find who is guilty or to blame anyone, but rather to find what happened and to extract lessons, to avoid future accidents. Kornati victims will never been forgotten and they will live in our memory, but we hope that lessons learned from the accident can help to further prevent such accidents. The accident of Kornati was the first accident in Croatia with a large number of causalities, but we hope that it will be also the last one, too.

Introduction

Croatia belongs to the group of European countries with high forest fire risk. In summer seasons seven coastal counties in Croatia and in particular the Adriatic islands are permanently exposed from high to very high fire risk, due to densely-spaced conifer forests, very warm climate with low level of humidity and a large number of tourists visiting various costal and insular regions. Because of that Croatia has a long history of organized fire fighting in both, professional and voluntary services. The first voluntary fire fighting organization in Croatia was established in 1864 in Varazdin. During this long history of fire fighting in Croatia, accidents with large number of causalities had never been recorded until the accident of Kornati in 2007.

According to official data, the fire season 2007 was one of the most severe fire seasons, but the reason why it will be forever remembered in Croatia is because on August 30th, 2007, the routine fire fighting operation on island Kornat in National Park Kornati islands ended with 12 dead and one badly injured fire fighters.

Shortly after the accident, in September 2007, in order to understand what could have happened during the Kornati accident the Office for National Security of Croatian Parliament and Ministry of Interior Affairs formed the voluntary research team composed of researchers from various Croatian Universities and institutions. The experienced research team from Forest Fire Laboratory of the University of Coimbra Portugal was also included and an independent scientific investigation was performed. The accident was primarily analyzed from meteorological, vegetation, fire spread, thermodynamics and aerodynamic points of view, but the fire fighters injuries, equipment, communication and fire fighting and rescue operation organization was analyzed as well.

The main task of this research was not to find who is guilty. That is eventually the task of official law-court investigation which is, at the end of August 2008, still in progress. The law-court in Sibenik has appointed its own independent team of court experts having the same task as our team – to analyze the fire spread and possible accident's causes. Until the end of the official law-court investigation, the integral report of court experts was not available yet. Publicly, only its short summary was presented at the end of August 2008. Although this chapter describes primarily the research of our independent scientific commission we will mention the main conclusions of the official court expert's analysis too.

After the accident there were a lot of speculations about its possible cause. This is for us a clear indication of the lack of understanding of the processes that are associated with these accidents. We must add that some of the explanations that are presented below were put forward by non expert persons, from the media or by common citizens. Most of them were connected with human artifacts. Let us mention few of them with additional comments why they have been officially declined:

An airplane bomb from the Second World War. (Comment - Around the accident place there was no one evidence of a bomb explosion, but also pathological analyses has not found any injury which could be caused by an explosion.).

The gasoline reservoirs explosion. (Comment - The firefighters carried with them two gasoline tanks, each one of 20 liters, but both of them did not explode the gasoline has burned as a torch.)

The helicopter accident. This theory said that the helicopter that carried the crew was damaged so it dropped its gasoline that sprayed on the fire fighters. (Comment – Official investigation of helicopter did not confirm such damage and found that its only damage was a broken tire of it landing gear.)

The mistake of helicopter pilot. This theory said that the pilot made a mistake activating the fuel bleeding procedure used when there is a danger of crash, so that the fire fighters were sprayed by fuel. (Comment - Official investigation of the helicopter declined this theory.)

Experimentation with the new NATO techniques for firefighting that included explosive devices in pipes used to generate water steam. The accident was caused by explosion because of bad equipment handling. (Comment - This theory does not hold by itself, but also because there were no evidences of any kind of explosion, both on terrain and on victims' bodies)

Experimentation with new explosive technique for firefighting based on small napalm bomb. (Comment – The same as before.)

Again explosion, but this time caused by military weapons and bombs. Ten years ago NATO had a military exercise close to Kornati islands, so one theory said that there were left over eventually lost or forgotten weapons or bombs on the island that exploded during the fire (Comment – The same as before.)

The last theory of explosion. It said that before National park period the army used Kornati for disposal of unused weapons so that the soil was polluted by explosive liquids or white phosphor. (Comment - Kornati islands are national park for 40 years, but also official investigation have not found any unusual material on the soil.)

Investigation and accident evidence analysis have declined all these, manmade causes or reasons of the accident. In spite of that, not only ordinary people, but also some professionals still did not believe that the grass vegetation on the island and natural phenomena could cause such a terrible accident.

Because of that the main task of our research was primarily to analyze if it was possible that the accident was caused by natural phenomena only. Our report ended with lessons learned from Kornati accident and 37 recommendations for further improvement of fire fighting organization, education and research in Croatia. We hope that the Croatian fire fighting services will be further improved and that the Kornati accident will be the first and the last such terrible accident in Croatia.

The research team has visited the accident place twice, on September 25^{th} 2007, when the weather conditions were similar to those on the day of accident and on February 5th 2008. Terrain configuration, local weather conditions and vegetation samples were collected and analyzed. In the remaining of this chapter we will shortly describe our research conclusions.

The accident place description

The island of Kornat is the largest of 365 islands in Croatia's Kornati National Park, a popular tourist resort. The fire ignition point was in Vrulje bay and the accident happened in the small canyon on the north side of Sipnate bay (Sipnate canyon). The canyon shown in Figure 4.1 is opened only from the south and on its other three sides it is surrounded by hills Glavica (135 m – west), Meja (150 m – north) and Veli vrh (212 m – east).

Injured fire-fighters were found on three places, marked with A, B and C in Figure 4.2. Six were found dead and seven injured. The injuries were very severe, so 17 days after the accident six badly injured fire-fighters passed away. Only one fire-fighter recovered completely.

During our first visit to the accident place in September 2007, when the weather conditions were quite similar to those during the accident, we noticed that in addition to the strong S-E wind, several aspects relating to the enclosed location played important roles in the accident, as described in detail in IWG (2008) and briefly in Stipanicev *et al*. (2008). The most important facts about the accident place are:

The location has stone terrain with no pathways and has a complex topography. It is a small canyon about 500 m long, closed from three sides, from east by Veli vrh hill (212 m), from north by Meja hill (150 m) and from west by Glavica hill (135 m) and open only from the south side (Figure 4.1).

The canyon's main axis is directed to the north, with 15% (9^o) average slope, and 29% (16^o) and 45% (24^o) maximum slopes on the left and right sides of canyon, respectively (Figure 4.3).

The total burned area located on the canyon bottom was 99 887 m^2 (ca. 10 ha).

The location has low-height and sparse vegetation, mostly grass, which in fitogeographic sense belongs to eumediterranian vegetation zone, with 35%–45% woody vegetation and total cover between 45%–55%. There are only a few small isolated trees and bushes (IWG, 2008; Spanjol *et al*., 2008).

The fuel load ranged from 0.561 kg/m^2 – 0.837 kg/m^2, and the average vegetation heat content was estimated to be 18,000 kJ/kg (IWG, 2008; Spanjol *et al*., 2008).

Vegetation was extremely dry and flammable, with ignition delay less than 2 s, and the average burning time of grass vegetation was 12 s (IWG, 2008; Spanjol *et al*., 2008).

Figure 4.1. Ignition point and the place of accident – the Sipnate canyon

Figure 4.2. Air photo of Sipnate canyon with marked places where fire-fighters were found. Upper part of hill Glavica was not burned (see Figure 4.5).

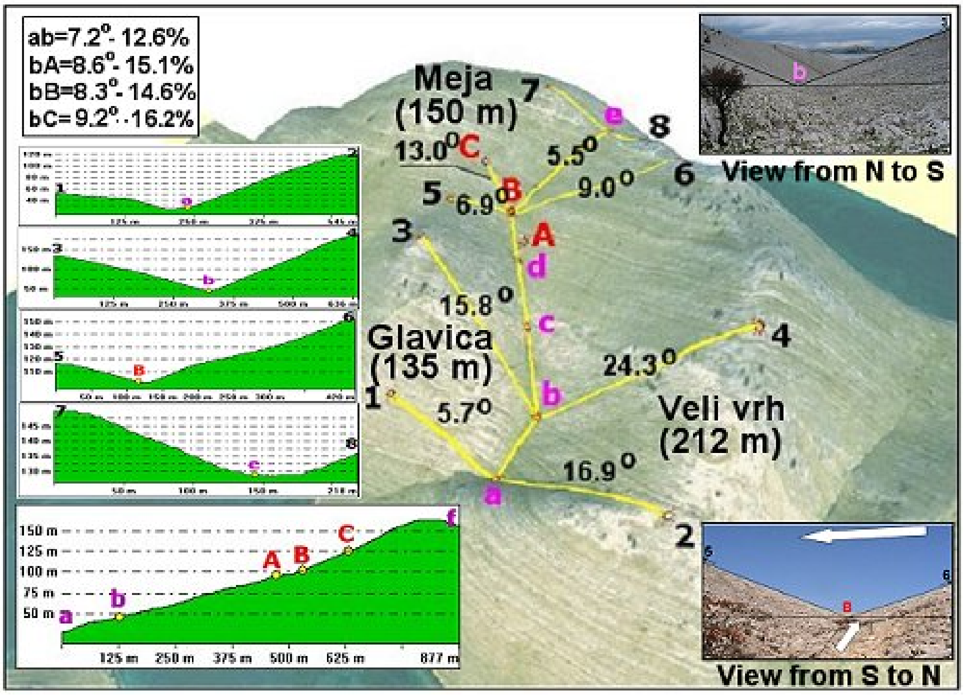

Figure 4.3. Sipnate canyon configuration with slope angles and canyon photos from north to south and vice versa

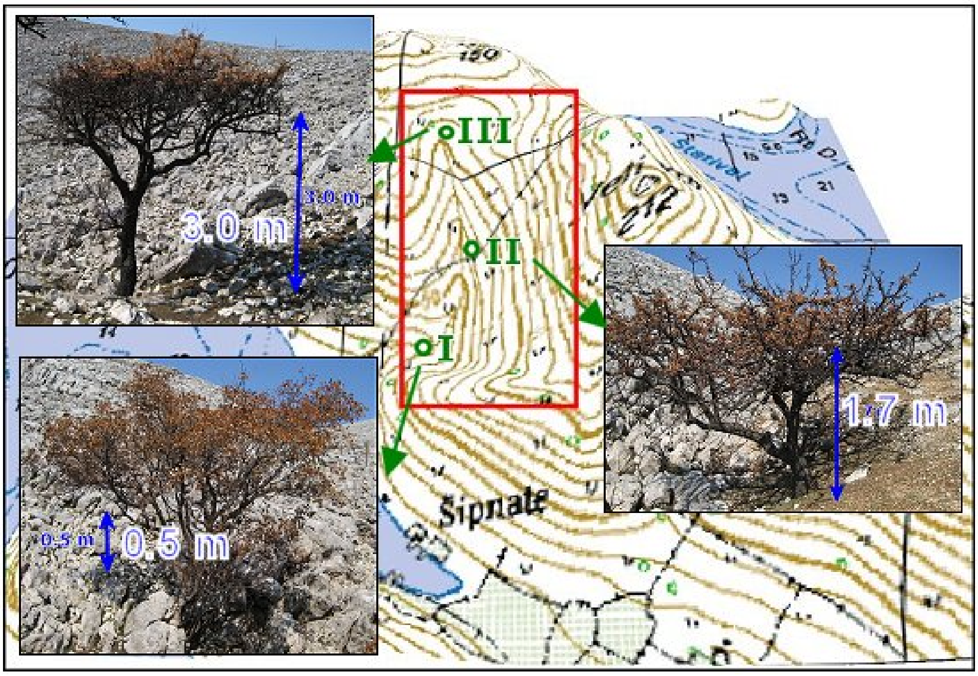

Figure 4.4. Unburned trees found on the line of canyon axis.

The humidity content of the grass vegetation ranged from 12% to 14% (IWG, 2008; Spanjol *et al*., 2008).

Dehydrated leaves on several trees showed the direction of the hot air flow from south to north (Figure 4.4).

Visible layers of burned and dehydrated bark, branches and leaves were present on several trees following the thermal boundary layer composition with heights from 0.5 m on the south side to 3.0 m on the north side of the canyon (Figure 4.4).

Glavica hill, settled on the west side, was unburned in its upper part (Figure 4.2), giving us the possibility to collect appropriate vegetation samples and analyzed them in laboratory (Figure 4.5).

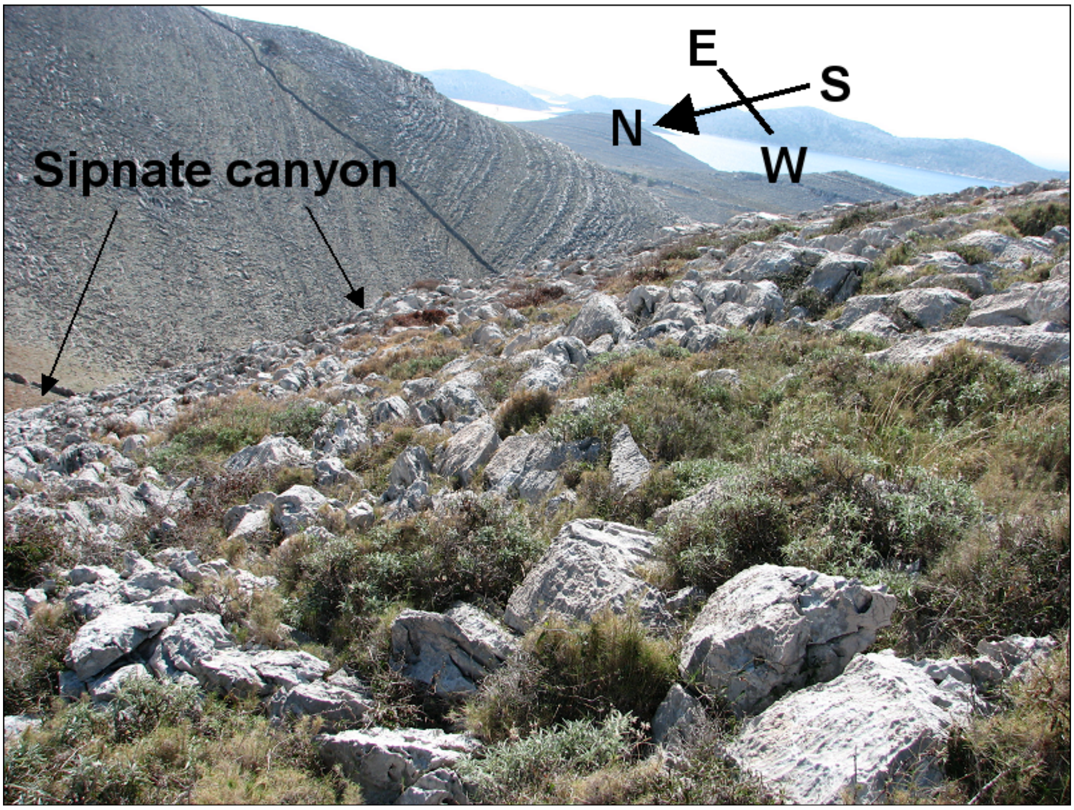

Figure 4.5. Unburned vegetation on the slopes of Glavice hill located on the west side of canyon.

Description of the accident

The official scenario of the accident was as follows:

11:00 – 11:30 - The fire begins in Vrulje bay 6.6 km south-east from Sipnate canyon, quite close to official building of Kornati National Park. The official investigation said that the fire was probably initiated by cigarette-stub thrown through the window by a seasonal employee of Kornati National Park.

11:48 – The first information about fire was received in Fire fighting operation centre in Sibenik. They sent the official request for helicopter.

11:50 – Fire fighters from professional brigade Sibenik, and voluntary organisations in Vodice, Tisno and Zablace start to prepare for helicopter departure.

12:00 – The helicopter was authorised.

13:00 – The helicopter takes off from Sibenik with 23 fire fighters.

13:15 – The helicopter landed on island Kornat near Kravljacice bay. Fire fighters were split in two groups. The first one composed of 6 fire fighters leave the helicopter here. They were not injured.

13:34 – The helicopter landed the second time between Lucice bay and Sipnate bay. The second fire fighters group composed of 17 fire fighters disembarked here.

13:40 – The commander of the terrain fire fighters group Dino Klaric contacted the professional brigade in Sibenik and said that they were waiting for water reservoir.

13:44 – Communication between Dino Klaric and Drazen Slavica – the county fire fighters commander. Mr. Klaric said that the situation is not simple: the fire front is very large, the grass was burning well and the fire spread speed was huge.

13:50 – The Canadair airplane start to fight the fire on island Kornat.

about 14:00 – The water container took off from Sibenik and 15 minutes later the reservoir was left on the south slopes of hill Veli vrh (see Figure 4.6).

14:30 – 14:45 – 13 fire fighters from the second group were brought by the helicopter from Sipnate bay to the new location. The helicopter tried to disembark them close to the water reservoir two times without success because of the strong wind from SE direction and the lack of space for the large helicopter to land safely on that place. The group commander Dino Klaric and the pilot then decided to disembark the fire fighters on a new location that was the top of Meja hill.

14:40 - The Canadair airplane was sent from Kornati to another location.

14:58 -The fire fighters were disembarked on the new location – the top of the Meja hill.

15:26 – The last communication with 13 fire fighters. Mirko Juricev Mikulin, a fire fighter from Vodice that was also in Kornat island contacted the professional brigade in Sibenik with an information that he had a contact with his son Ante (who was in the group of 13 fire fighters) who said to him that the group of 13 fire fighters was surrounded by the fire.

16:25 – Josko Knezevic contacted Operation centre in Sibenik and asked urgently for an helicopter. He had a contact with Marko Knezevic who said to him that there were burned and injured fire fighters.

16:50 – The first rescue helicopter leave Divulje. Its crew located injured fire fighters but it was not equipped for an air rescue on that terrain.

17:35 – Fire fighters from the first group reached the Sipnate canyon.

18:00 – The voluntary Mountain rescue service from Split started the rescue operation.

19:40 – The last fire fighter was taken off from Kornat island.

The professional fire fighters from Sibenik brigade made a reconstruction of the accident in Sipnate canyon using photos from a portable telephone camera found on the accident place belonging to Tomislav Crvelin. The reconstruction is schematically shown in Figure 4.6. The group of 13 firefighters landed on the top of Meja hill and the water container was left on the south slopes of the Veli vrh hill. The straight line air distance between the embarkation point and water reservoir location is 928 m, but as the terrain is not flat, the shortest pedestrian distance is almost doubled. All firefighting equipment that was carried by the group on board of the helicopter was disembarked. They carried some motor pumps, back-pack hand pumps, fuel containers and other tools but they did not have water that was in the reservoir on the top of the other hill. The fire fighters started to walk on the very difficult terrain of the island in the direction of the water container to start attacking the fire using the shortest path. When they started their walk the fire front location was not visible for them.

On their way they found that the fire line was along the crest of the ridge of the Veli vrh hill. This fire line is clearly visible on the photo taken by one firefighter before the accident and shown in Figure 4.7. Probably the fire fighters decided then to turn to the right and walk away from the fire to go around it. In the process of surrounding the fire line, the group started to descend along the eastern slope of Sipnate canyon and to actually place them near point *A* at the water line of this canyon shown in Figure 4.3. Certainly unknown to them the southernmost edge of the fire line had probably entered the base of the canyon much below their position. Given the configuration of the canyon and the curvature of its water line from the position *A* the group could not see the bottom of the canyon. Therefore they must have realized that the fire was below them quite late to have a chance to escape collectively. Most of the equipment was dropped by the fire fighters near point *A*. It was also near this point that the majority of the victims were found. The only survivor was a fire fighter that remained slightly behind the group and escaped from the very intense and quick fire updraft along the canyon. A small group of fire fighters managed to reach point *B* but were found dead there. Remarkably a fire fighter was able to run until point *C* in spite of the extremely difficult terrain conditions but he was overwhelmed by the hot gases produced by the fire and caught by the fire spreading from East driven by the strong winds created by the main fire on the West slope of Sipnate canyon.

This reconstruction coincides with the interview with Frane Lucic, the only one firefighter from this group who has survived the accident of Kornati (Kljakovic and Markovic, 2007). In one part of this interview Frane Lucic said: *"The grass was up to our knees. But the important fact was the very strong wind. In the canyon where we were found, the wind has changed its direction and formed the fire front in crescent moon shape reaching us with very high speed – maybe six, seven m/s. The grass was dry as gunpowder. We saw that flames and very thick smoke are going in our direction with high speed. We were left without breathing air. We started to run. We threw away our equipment to run faster. I was responsible for the rucksack with food, so I threw it away. I ran as fast as possible. Me and fire, but the fire was quicker. In a moment I was hit by the fire but I had enough time to put down the shield on my helmet and that has saved my face. Then my legs were overtaken. I have been burned but in a fragment of second I jumped into the burned grass behind me. The heat has violently burned my fists but that movement has saved my life. Practically I stop running from the fire, turned myself toward the fire direction and went through the fire. After five to six steps I found myself on burned land, out of hell. But my friends were not so lucky."*

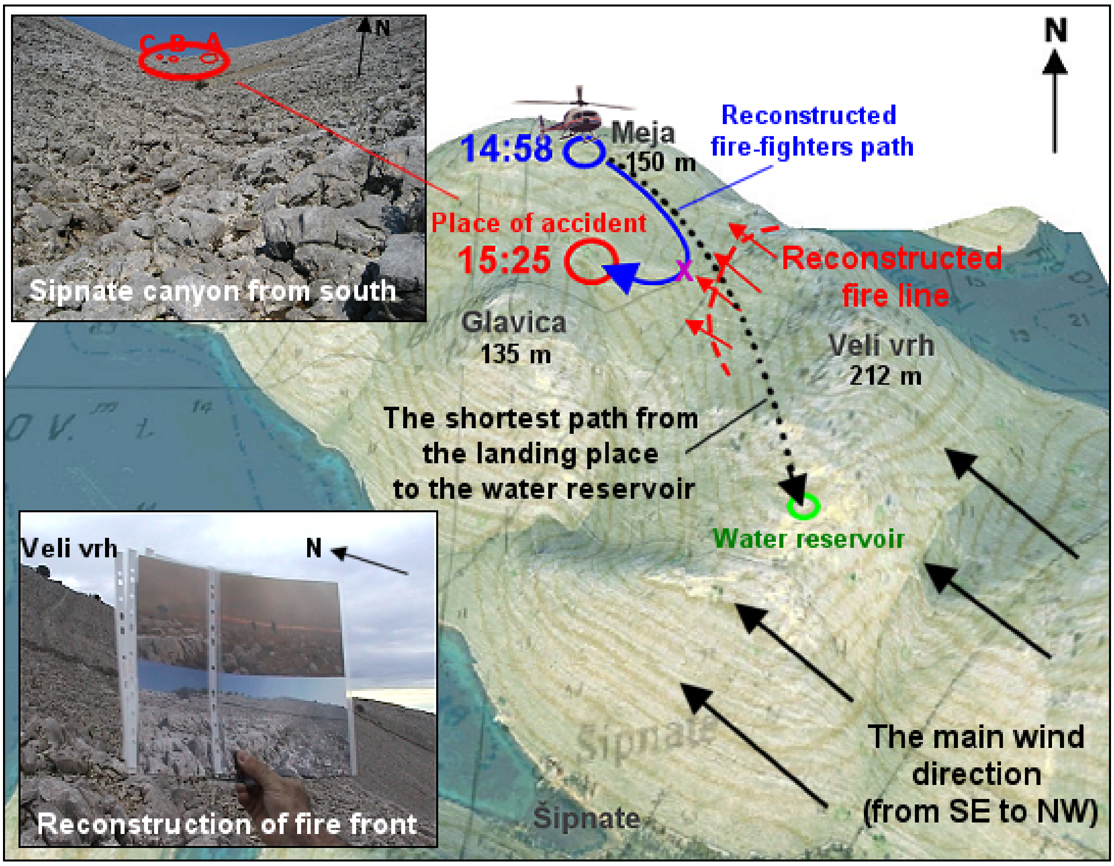

Figure 4.6. The location of the accident and important facts about the accident, including fire front reconstruction from photos taken by fire fighters half an hour before the accident

Figure 4.7. Photo from the camera found on the accident place. According to reconstruction the photo was taken on the west slopes of Veli vrh hill. The fire front came from the east and it blocked the fire fighter path to the water reservoir.

Meteorology situation during the accident

The researchers from the Meteorological and Hydrological Service of Croatia have analyzed the meteorological situation during the accident in detail (IWG, 2008; Vucetic *et al*., 2008; Vucetic, 2008). Here only a short summary of those reports, that are important for further accident analysis is presented.

On August 30th 2007 there was a shallow meso-cyclone over the Zadar area (cca. 30 km straight line aerial distance) which produced sultry, partly cloudy and windy weather, with moderate to strong *jugo* (SE wind) and visibility limited to 10 km.

The temperature in Zadar was 26°C, with maximum of 29°C in afternoon. The relative air humidity was between 55% and 70%. Because of cloudy sky the sun radiation has varied between 5 kJ/m^2 and 55 kJ/m^2.

Gusts of *jugo* exceeding 10 m/s (36 km/h) at 10 m height were recorded in Zadar between 10 and 16 hrs. The maximal wind gust was 15.9 m/s (57 km/h) recorded at 13.20h. The maximal 10-minutes average wind speed value was 11.6 m/s (42 km/h) recorded soon after the maximal wind gust.

There are no wind measurements from the accident place, but the wind speed and direction in accident area was simulated using two models: ALADIN/HR and MM5. According to them, at 10 m height in the accident area the wind was from SE direction and wind speed varied between 5.5 m/s and 10.8 m/s (19.8 km/h and 39 km/h).

The MM5 model simulations of the vertical structure of the atmosphere showed that the weather in the lower layers of the troposphere was favorable for the development and spread of the fire.

The MM5 model simulations also showed a sudden increase in wind speed to 12–14 m/s in the first 100–200 m height above the mean sea level, indicating the low-level jet stream with a very strong vertical wind shear in this layer, whereas very high values of turbulent kinetic energy and strong turbulence in the canyon. Above this layer, a layer of temperature inversion was formed, about 300 m thick, preventing further updraft movements in the lower layer. In the inversion layer, wind speed rapidly decreased and the direction turned to S.

As the largest amount of humid air penetrated only up at 500 m, strong convective cloud development did not take place on August 30th 2007.

The Canadian Forest Fire Weather Index System for the Zadar station has shown that FWI *(Fire Weather Index)* and ISI *(Initial Spread Index)* reached their maximum precisely on August 30th 2007. Their values were 66.6 and 31.8, respectively. The FFMC (*Fine Fuel Moisture Code)* value on August 30th 2007 was 88.5, which would indicate a moisture content of the fine fuel mass equal to 10–12%.

Fire propagation simulation before and during the accident

The fire began between 11:00 and 11:30 at Vrulje bay, located 6.6 km SE of the Sipnate canyon. The accident happened between 15:20 and 15:30, so the average fire Rate of Spread (ROS) was of the order of 0.46 m/s (1.66 km/h, 46 cm/s).

At the University of Split, we developed a fire propagation simulator iForestFire® (Stipaničev *et al.* 2008; iForestFire, 2008), based on Rothermel equations and cellular automata, particularly adapted for the Croatian coast and islands, so we used it to simulate the spread of Kornat island fire. During data preparation for simulation the largest problem was how to derive the appropriate vegetation map, because Croatian vegetation had never been analyzed according to fire spread characteristics. Our approach was to use standard Kornat island vegetation maps and Kornat CORINE 2000 land cover-land use classification and replace their vegetation categories with fuel models proposed by Albini-Anderson (Anderson, 1982) and Scott and Burgan (2005). During our research, many simulations were performed to find appropriate input parameters that would best fit the observed data, particularly the fire's time of arrival at the accident location and average ROS of 0.46 m/s. For the main fuel category defined by Albini-Anderson as fuel model type 1 (short grass 1 foot) and dead fuel humidity 12% the best fit was obtained for mid-flame wind speed 2.29 m/s (Figure 4.8).

The most important conclusion derived from all our simulations was that the fire front propagated faster on the north side of Kornat island. Witnesses have mentioned this as well, and this fact was used in the reconstruction of the firefighters' path, shown in Figure 4.6. According to simulation, the south part of fire has propagated slower entering to the south part of Sipnate canyon after the fire front had reached the top of the hill Veli vrh.

The second part of our fire propagation analysis was the fire spread inside Sipnate canyon. In Sipnate canyon, the dominant vegetation type was very dry grass. Fuel load estimation, based on vegetation sampling was 0.561 kg/m^2 – 0.837 kg/m^2 (IWG, 2008; Spanjol *et al*., 2008). The most similar standard grass vegetation categories close to this fuel load are Albini-Anderson fuel model type 3 (A-A M3) with a fuel load of 0.744 kg/m^2 (Anderson, 1982), and the Scott-Burgan fuel model GR4 (S-B GR4) with a fuel load of 0.531 kg/m^2 (Scott and Burgan, 2005). In Sipnate canyon, the mid-flame wind direction was parallel to the main canyon axis and mid-flame speed was 1.8 m/s – 4 m/s (6.4 km/h – 14.4 km/h). These values were calculated using Anderson methods from 10 m wind speed obtained by meteorological simulation models. Fine Fuel Moisture Content (FFMC) was 12% – 14% and moisture in live grass fuel was 30%. The Dead Fuel Moisture of Extinction (ME) was estimated to be 40% because the original ME values for A-A M3 (25%) and S-B GR4 (15%) fuel models were not appropriate. The same problem for Mediterranean vegetation was also noted by Yebra et al (2007). Their ME estimation for grass vegetation of 40% corresponds to our experience too. The average slope of Sipnate canyon's main axis is 14%.

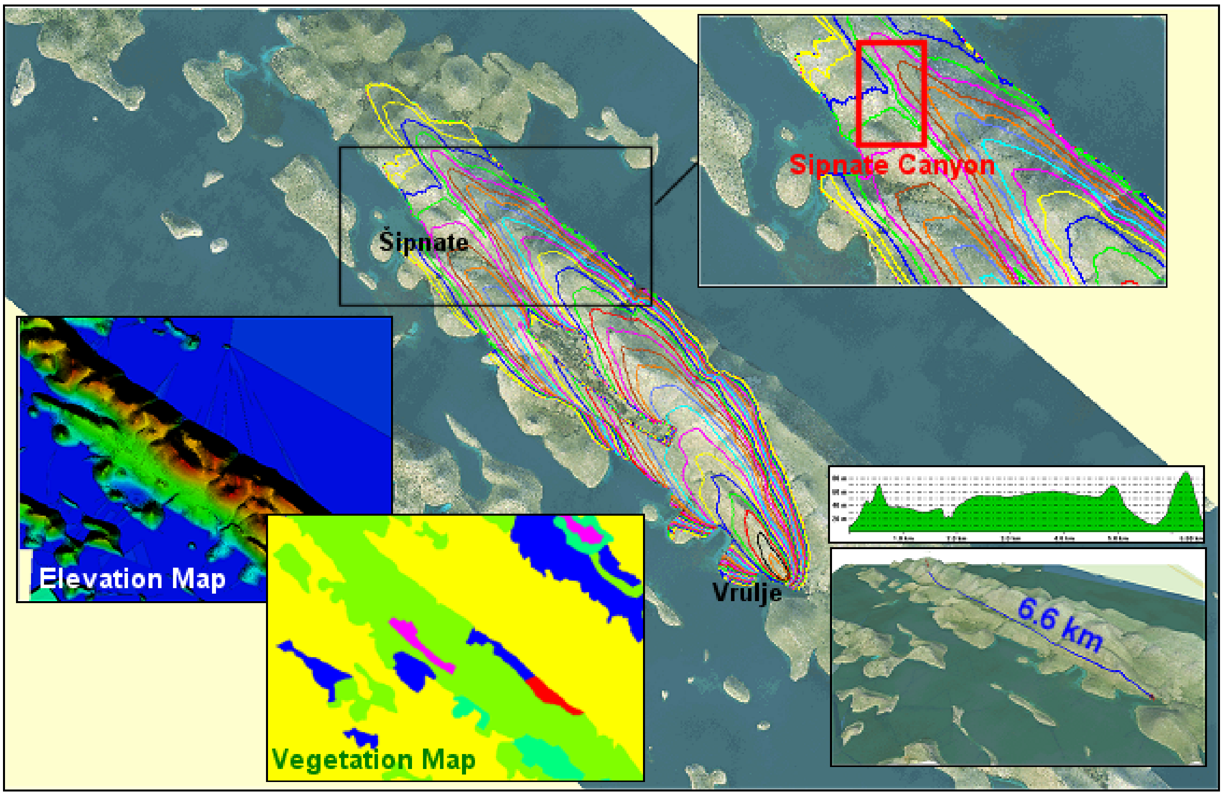

Figure 4.8. Fire spread simulation from the ignition point at Vrulje bay to the location of accident at Sipnate canyon based on Rothermel equations and adapted for Croatia at the University of Split. The dominant vegetation (light green) was modeled by Albini-Anderson category 1 (short grass), dead fuel humidity was 12% and average mid-flame wind speed 2.29 m/s.

Fire propagation parameters were calculated using the BehavePlus3 simulation program, and results for A-A M3 and S-B GR4 fuel models and FFMC 12% are given in Table 1. The burned area at the bottom of the canyon was about 10 ha, so the total released heat energy caused by vegetation burning could be estimated to 550 GJ – 750 GJ. The Rothermel equations and the BehavePlus3 program suppose a constant rate of spread for the fire, and according to them, arrival time from the point visible from the accident to the location of the accident (distance 350 m) is between 5.21 min to 15.91 min, which is not realistic.

The firefighters were quite experienced, so if the arrival time of the fire front in Sipnate canyon was between 5 to 15 minutes, they would have had enough time to escape. Thus, our conclusion was that the Rothermel model with constant fire rate of spread was not appropriate for simulation the fire behaviour in Sipnate canyon. Another possibility was eruptive fire model that was proposed in Viegas (2005). A simulation of Sipnate fire was performed at the University of Coimbra Forest Fire laboratory and the results were applied in eruptive fire mathematical model.

Table 4.1. Fire propagation parameters in the canyon for Albini-Anderson type 3 and Scott-Burgan GR4 fuel categories and various mid-flame wind speed

A-A M.3

Midflame Wind Speed km/h	Rate of Spread m/min	Heat per Unit Area kJ/m2	Fireline Intensity kW/m	Flame Length m	Reaction Intensity kW/m2	Spread Distance m
6.4	23.9	7963	3168	3.2	518	1432.4
9.6	39.2	7963	5205	4.0	518	2353.1
14.4	65.3	7963	8670	5.0	518	3919.6

S-B GR4

Midflame Wind Speed km/h	Rate of Spread m/min	Heat per Unit Area kJ/m2	Fireline Intensity kW/m	Flame Length m	Reaction Intensity kW/m2	Spread Distance m
6.4	22.0	5123	1877	2.5	406	1319.2
9.6	38.1	5123	3252	3.2	406	2285.4
14.4	67.2	5123	5735	4.1	406	4030.1

Laboratory simulation of fire and eruptive fire mathematical model

A laboratory simulation of the fire evolution in Sipnate canyon was performed at the Forest Fire Laboratory of the University of Coimbra at its large canyon table DE4. Only few details of the experimental conditions are given here. The Table has two faces that were set at the inclination angles given in Figure 4.9 in order to represent the basic shape of the lower part of the canyon. The fuel that was used in the tests was straw that replicated well the combustibility properties of the herbaceous fuel that existed largely in the area. An ignition line was set at the position shown in the same figure.

Video and infra-red cameras were used to register the experiments. Several experiments were carried out with slight differences in the pattern of ignition. The evolution of the fire front along the three main directions SL, S1 and S3 was analyzed from the IR images and the results are shown in Figure 4.10. As can be seen in this figure the linear fire front propagated relatively slowly down slope towards the canyon water line (direction SL) but when it reached this line and the bottom of the eastern slope of the canyon it spread very rapidly along it (line S3) and along the water line (S1). Given the differences in scale and configuration we do not claim that these experiments replicate with great precision the fire spread conditions before and during the accident but they do show some very important qualitative features of the fire in this process.

We can see that the spread along S3 exhibits an acceleration that is characteristic of eruptive fire behaviour. In our opinion this was most likely to have occurred in Sipnate canyon before the accident. One other point that we can see in that figure is that the fire spread along the water line (line S1) was also very quick and it happened almost at the same time as the other eruption. This is consistent with the facts that the group of fire fighters was caught near the water line and on the West side of it.

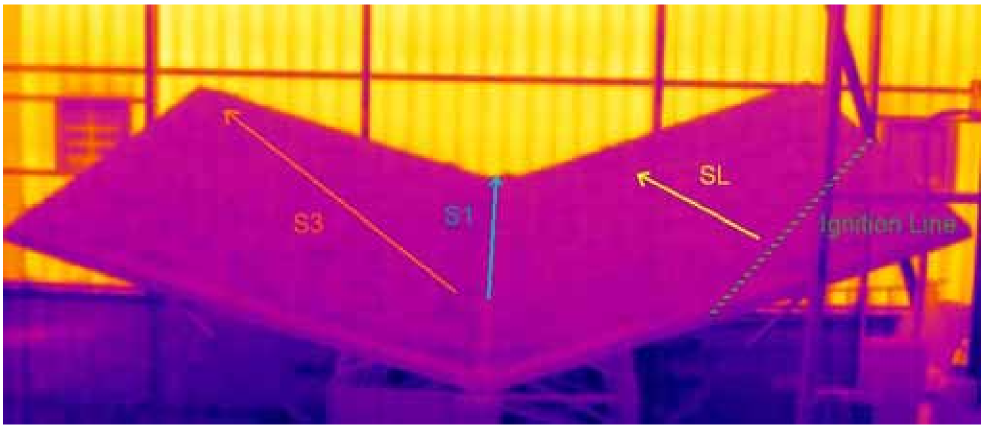

Figure 4.9. Schematic view of the Canyon Table of the Forest Fire Laboratory of the University of Coimbra indicating the position of the ignition line and the three directions S1, SL, and S3 along which the fire spread was analyzed.

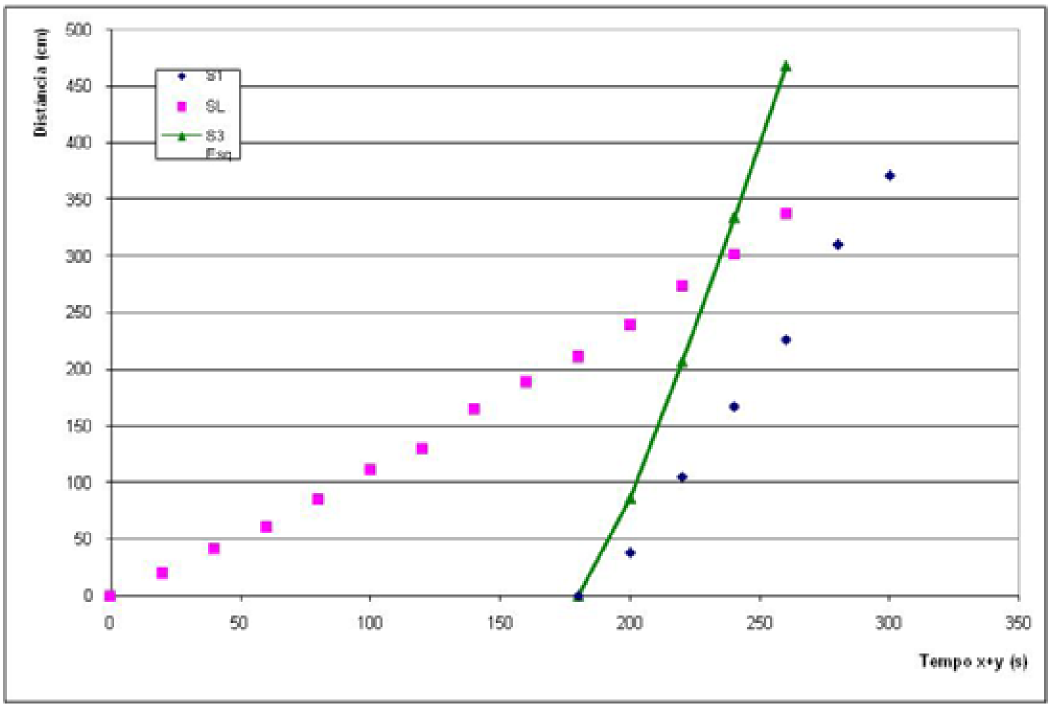

Figure 4.10. Distance traveled by the fire along the three main directions indicated in Figure 4.9.

We remark that in this test no wind was used over the test area. Comparing with the actual situation of the accident we know that the presence of a relatively strong wind aligned with Sipnate canyon would make these conditions even worse.

Given the evidence of the very likely existence of an eruptive propagation of the fire in Sipnate canyon we shall apply the mathematical model (Viegas, 2005; 2006) to predict the rate of spread of the head fire in this case. In spite of the simplicity of the mathematical model it is necessary to know the adequate parameters and initial conditions in order to apply it. As the properties of the fuel bed that existed in Kornat Island are not yet well known we can only apply the parameters that were measured for similar fuels assuming that they are analogous to the conditions in Sipnate canyon. We shall use the following set of parameters in order to apply the mathematical model to estimate the advance of the head fire along the water line of the canyon and along the left (East) slope of the canyon.

Table 4.2. Parameters used in eruptive fire mathematical model

R_o (cm/s)	R'_i	t_o (s)	b_1	b_2	a'_1	a'_2
0.61	1.5	50	1.8	1.0	0.2	0.2

Using the above mentioned values the differential equation of the rate of spread was integrated twice to determine the distance of advance of the head fire since its arrival at the water line of the canyon (at point *a* of Figure 4.3) and the result is shown in Figure 4.11. The relevant points of the trajectory of the head fire along the water line of the canyon are indicated on the curve.

If the prediction that is indicated in this figure is correct we can see that since the fire entered the base of the canyon it may have taken some minutes to reach point *b*, but from this point onwards it must have taken less than two minutes to reach the main group at positions *A* and *B*. In less than three minutes it must have reached position *C*. These time intervals are consistent with the distances and displacement times that would be required to travel from *A* to *B* and to *C*. If we assume a displacement velocity of 2m/s for the escaping fire fighters they would require between one and three minutes to reach from *A* to *B* or to *C* respectively, taking into account the difficulties of the terrain.

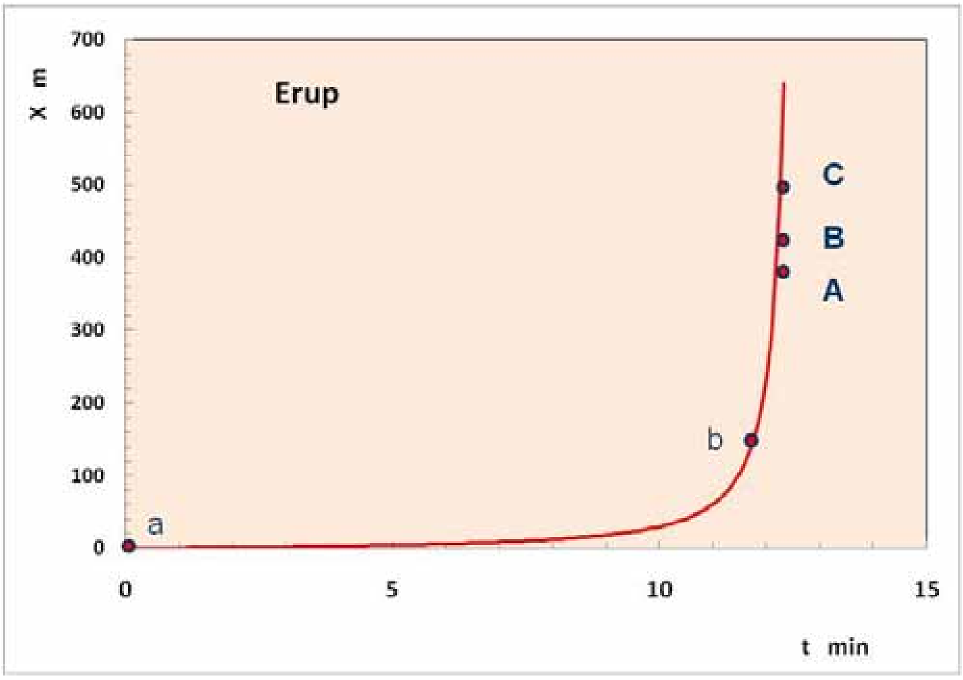

Figure 4.11. Predicted distance of advance of the fire along the water line of Sipnate canyon with time since its entrance at the base of the canyon at point *a*.

We remark that the presence of flames at the bottom of the canyon could only be perceived when the fire reached point *b*, although we can assume that the presence of smoke could have been perceived a bit earlier and might have triggered the alarm one or two minutes before. Even so it was probably too late for the group to reach a safe zone near their current position.

In this simulation we also did not consider the effect of the wind on the fire eruption. Based on our previous observations we assume that the presence of wind might anticipate the moment of eruption but would not otherwise change the sequence of events. The eruption would have occurred with the support of the wind giving even less time for the group to escape from the fire.

Aerodynamic and thermodynamic aspects of accident

The basic aerodynamic and thermodynamic analyses of the fire evolution in Sipnate Canyon was also performed (IWG, 2008; Klarin, 2008; Ninic and Nizetic, 2008) based on a number of assumptions (Klarin et al, 2008). We give here a brief summary of the results of this study that is complementary to ours. The most important conclusion of the aerodynamic and thermodynamic analysis is that if we use only the standard assumptions of fire development, excluding the eruptive fire propagation effect, there is not enough flow energy and gas expansion in a grassy landscape fire development that could result in such a violent accident and so severe injuries. Other assumptions based on the accident place analysis are as follows:

Stones on the terrain are large, with high grass in between. It is not easy to walk or to run on this terrain, especially for heavily loaded and equipped fire fighters. Only short jumps are possible as a means to move around. Natural stone walls up to 5 m high serve as obstacles; therefore, fire fighters must follow the directions of these stone walls.

Veli Vrh hill is the main terrain obstacle for air flow above the canyon. Its side line is almost perpendicular to Kornati Island's main axis. It could be expected that the main air flow bypasses the peak. Because of the relative canyon depth, large eddies can be produced over the canyon. This means there is local backward flow.

The canyon over Sipnate Bay has its main axis in the north-south direction. The canyon begins at sea level with the main part just below Veli Vrh hill side. The canyon end is on the north side, just below the maximum jet stream layer. On this side there is a small plateau located between Veli Vrh and Meja. On the east side of the canyon lies a flat skew plain, which was the location of the accident. The main thermal boundary layer was developed here.

The surface jet stream layer over the complex terrain caused tunnelling of the hot air flow and renders analysis very complex. Therefore, some reasonable assumptions have to be made in order to achieve satisfactory results.

There are two factors that aid the analysis. The first is the presence of dehydrated leaves on several trees in the path of the hot air flow. The hot air speed does not allow for burning, but only for heat transfer, which dries up leaves. Few other places in surrounding locations are visible with dry leaves in different paths.

Another aiding fact are the visible layers on several small trees, composed of burned and dehydrated bark, branches and leaves, following the thermal boundary layer development from the bottom of the canyon (0.5 m) up to the middle part (1.7 m) and the plateau at its end (3.0 m). These heights provide iterative backward analysis of the thermal boundary layer.

Half of Glavica hill was unburned due to backward flow caused by a large eddy, and the peak of Veli Vrh was partly unburned, probably due to a strong wind in the surface jet stream.

The first canyon section is not visible from the location of the accident.

During our first visit to the accident place at the end of September 2007, the wind conditions were similar to those during the accident. We noticed two wind streams: the first one was dominant from the SE direction, blowing over the edges of Veli vrh hill, while the second one was following the water line of the canyon blowing from S to N. The first dominant wind stream was much stronger on the N side of the canyon Top side). At the bottom of the canyon, close to its southern entrance, the wind stream from SE was not present. Only the second wind stream which followed the canyon water line could be noticed.

Two possible thermodynamic explanations of the accident were given in the above mentioned studies:

The theory of Fast Heat Shock (FHS) derived during accident investigation by voluntary scientific research team established by Office for National Security of Croatian Parliament and Ministry of Interior Affairs (IWG, 2008; Ninic and Nizetic, 2008; Klarin, et al., 2008).

The theory of "burning of non-homogenous gas mixture", derived by court expert team. Their theory has not been yet published with all details, because the court experts report is an integral part of court investigation which is still not finished, but its summary was given (HINA, 2008).

Fast Heat Shock Theory

This thermodynamic analysis was based on the assumption that the downwind terrain section was quickly burned. However, a fast inflammation effect is not sufficient to explain the accident, particularly the firefighters' severe injuries. Therefore, after analyzing all the evidence, Ninic and Nizetic derived one possible explanation, called the Fast Heat Shock (FHS) that is explained in detail in (IWG, 2008; Ninic and Nizetic, 2008; Klarin, et al., 2008).

According to their theory, the fire fighters may have been surrounded by the flames or in the enclosure of the rapidly shifted fire front. In any case, at the moment of inflammation of section at the bottom of Sipnate canyon, this modeling of the accident includes fast heat input along the whole canyon section. This heat input caused temperature-turbulent boundary layer formation. Its thickness at the location of the accident was 2.5 m, known as the height of the dehydrated leaves on small trees in the area. As the primarily research goal was to estimate only the possibility of an accident due to natural causes, relatively unfavorable circumstances were assumed, as for example a relatively low air excess factor $\lambda=1.5$, a local air speed at 2.5 m above the ground was estimated to be 10 m/s, and dry grassy fuel load was estimated to be 0.6 kg/m^2. With the assumed effective flame temperature and ignited section length, this input data provided an iterative estimate of the mean temperature in a boundary layer at the accident location.

Energy balance for the flow through a rectangular cross section space of length 300 – 350 m and height 2.5 m, was calculated. For typical accident input data, the calculated average hot wind temperature was at least 420 K (150° C) and the duration was 2-3 minutes. Results show that this mechanism, called 'FHS - Fast Heat Shock', could explain the unusually violent consequences from apparently harmless circumstances. This explanation is independent of the fast inflammation mechanism.

Burning of non-homogenous gas mixture

As we don't know all details we cannot discuss this theory in deep, so we will shortly present the official report summary given to the press by judge investigator Branko Ivic on August 22, 2008 (HINA, 2008) (the translation into English is ours):

"The Kornati accident was caused by a natural phenomenon known as 'burning of non homogenous gas mixture'. The gas mixture was created as a result of few hours burning of Kornati grass vegetation from the fire ignition point (Vrulje bay) to accident place (Sipnate canyon). The distance between them is more than 6.5 km. As a result of vegetation burning, gasses and vapor composed of hydrogen, methane, ethane, CO, methanol and others were produced. They were carried by wind over the top of hill Veli vrh and started to concentrate and accumulate in Sipnate canyon. One fire front entered the Sipnate canyon from its south part. Fire propagation through canyon probably had the

eruptive fire behavior, so the fire front has reached the accumulated gas mixture in Sipnate canyon rather quickly and burned it.

The characteristic of natural phenomenon known as 'burning of non-homogenous gas mixture' is high temperature burning, sometimes more than 1200 ^{o}C. Also one of its consequences is a very fast expansion of hot gases. During this expansion their volume could be increased five to eight times in relation to their initial volume. The firefighters were first exposed to hot gases and after that to flames of burning vegetation, equipment and cloths. 'Non-homogenous gas burning' was the primarily cause of fire fighters injuries. It is a very rare natural process but not unknown. A similar thing happened in Australia January 18, 2008 close to Canberra and on September 17th 2000 near Palasca at Corsica.

The experts also found that the helicopter has no connection with the accident and that there were no any other kind of explosive devices – mines, bombs or phosphor as was speculated before."

The members of the court expert group were *M.Drakulic, M.Carevic, B.Grisogono, S.Kocian, V.Mastruko, D.Zecevic and others*. In the future, when their integral report, will be publicly available, we can discuss this theory in more details. Here, we only mention that we have considered the accumulated gas theory described by Peuch (2007) in our original report (IWG, 2008). After analysis we did not consider it as a good explanation of this accident, particularly because during our first visit to the accident place we have noticed two wind streams – the dominant one from SE, and local one in canyon which followed the canyon water line. Our conclusion was that with these wind condition the gas accumulation was not possible in the canyon, but we will reconsider this theory again when details of court expertise will be available.

Lessons learned and conclusions

What we have learned from this accident? The most important conclusion is that any fire fighting intervention can be potentially dangerous, so it is necessary to apply all measures of precautions. The Kornati fire looked at the first sight quite a simple fire because fuel was mostly short grass. The fire fighters said that the fire front on its way from Vrulje to Sipnat was not severe, so they have crossed the fire line several times. But the vegetation fire is such a complex phenomenon that usually it is not so easy to predict its further development. Good fire fighters training and preparation, but also maximal concentration during intervention is vital for successful and safe fire fighting operations.

In this chapter our interest was primarily focused on a technical explanation of the accident, but during investigation some organizational and procedural aspects in fire prevention and fire fighting procedures that can be improved were recorded. For example:

- The fire protection in National park Kornati was not appropriately organized according to existing plans.
- The fire fighters radio communication was not completely functional.
- Fire fighters were not wearing the complete working uniform resistant to fire.
- Some organizational problems were reported, for example two fire fighters were youngsters, although according to Croatian law youngsters could not participate in fire fighting intervention.
- In summer 2007 Croatia had only 4 Canadair airplanes for attacking forest fires. At the end of August, two of them were out of order for repair and one was sent to Greece as a help, although the summer 2007 was very dry and at the end of August the fire danger index was very high. Only one airplane was in operation in Croatia. On August 30, 2007, two other large fires were active in the region, so at 14:40h the airplane was sent from Kornati to another location.
- The rescue operation of the victims was not organized appropriately, because the system was not prepared for such a disaster.

Also many questions were raised about the decision where to attack the Kornat fire. For lot of people, particularly families of victims, but also some professionals, it is still not clear why the decision was taken to attack the fire front instead of protecting rare houses and rare fields of olive trees. For centuries Kornat islands were used for sheep pasture, so it was well known that shepherds used to burn the island to recover the grass. Houses are located only at isolated bays close to the sea and it was quite easy to protect them from the fire. A couple of months after the fire, the grass vegetation on Kornat islands had regenerated almost completely.

After a detailed analysis of all aspects of Kornati accident we have concluded our report with 37 recommendations concerning fire fighting education, fire fighting intervention organization and forest fire research, but also a number of recommendations concerning fire fighters equipment, communication and global organization were given too. Until 2007, in almost century and half long history of fire fighting in Croatia, an accident with such causalities had never been recorded. We hope that our recommendation will be accepted by authorities in order to further improve fire fighting in Croatia. The accident of Kornati was the first one such accident in Croatia, but we hope that it will be also the last one. We must also refer that as a consequence of this accident at least two events were organized in 2008 by the Croatian authorities for the leaders of fire fighting services of Croatia and of neighbouring countries in which the authors had the possibility of presenting the results of this research and therefore to contribute to a better education of Croatian firefighters to avoid future accidents.

Acknowledgment

Our research of Kornati accident is dedicated, not only to Kornati victims *Ante Crvelin, Ivica Crvelin, Tomislav Crvelin, Ante Juricev-Mikulin, Dino Klaric, Marinko Knezevic, Josip Lucic, Ivan Marinovic, Karlo Severdija, Gabrijel Skocic, Marko Stancic, Hrvoje. Strikoman and survived fire fighter Frane Lucic*, but also to all other victims of fire fighting accidents. Lives of brave firefighters are lost forever, but if we will be able to understand what happened in Sipnate canyon, maybe we will be able to prevent similar accidents in the future.

In this research several Croatian and Portuguese scientists and researchers were involved, primarily *N.Ninic, B.Klarin, S.Nizetic, Lj.Bodrozic, M.Stula, D.Krstinic, T.Jakovcevic, M.Sikora* from Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, University of Split, Split, Croatia, *M.Vucetic, B.Ivancanin-Picek, M.Mokoric, M.Tudor, S.Ivatek-Sahdan, L.Kraljevic, N.Strelac-Mahovic, T.Trosic* from Meteorological and Hydrological Service of Croatia, Zagreb, Croatia, *Z.Spanjol, R.Rosavec* from Faculty of Forestry, University of Zagreb, Zagreb, Croatia and *L.M.da Silva Ribeiro, L.Paulo Pita and C.Rossa* from ADAI (Associação para o Desenvolvimento da Aerodinâmica Industrial) University of Coimbra, Coimbra, Portugal.

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5. The Palasca Fire, September 2000: Eruption or Flashover?

John Dold, Albert Simeoni, Anna Zinoviev, Rodney Weber

At 6:57 am, about ten minutes before sunrise in the early morning of 17th September 2000, a fire was reported near the base of a relatively small incised valley in northern Corsica. Starting beside a coastal road, the valley rises almost 200 metres, in a north-easterly direction, over a distance of about 700 metres, to a ridge that separates it from another valley falling away sharply to the north east. A photograph of the valley is shown in Figure 5.1, as viewed from Lozari beach which can be seen in the satellite image of the region that is shown in Figure 5.2.

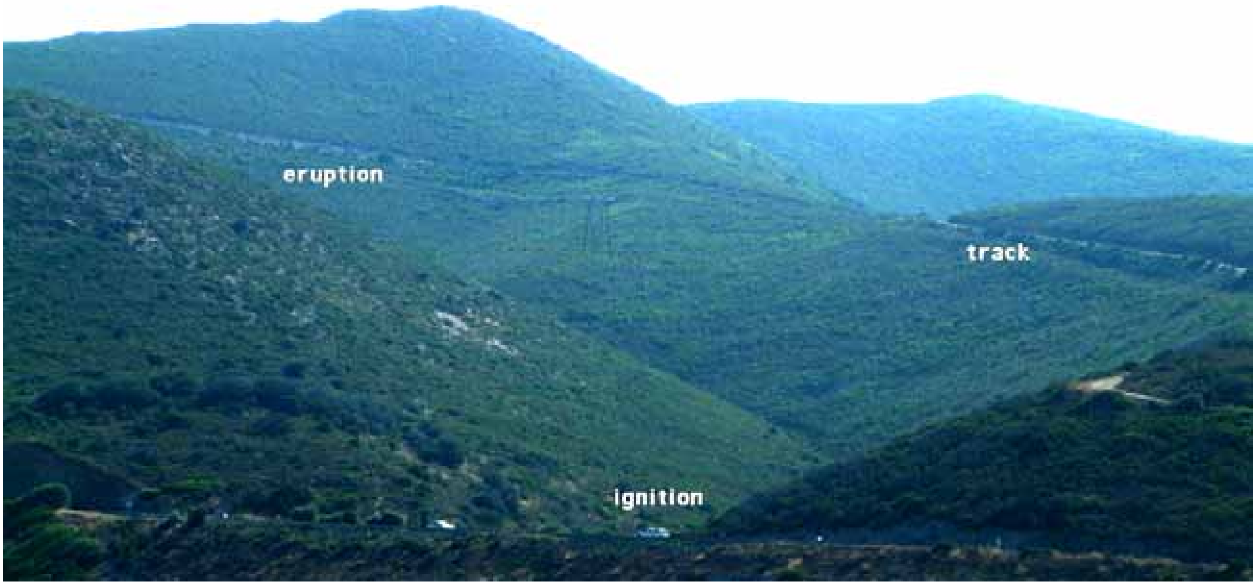

Figure 5.1. A photograph (from Lozari beach) of the valley in which a dramatic acceleration in fire spread occurred on 17th September 2000, up the slope marked 'eruption'. The track used by fire crews to access the valley and the region where the fire was ignited are also marked.

Figure 5.2. A satellite image showing the valley seen in Figure 1 as well as the nearby Lozari beach. The track used by fire crews to access the valley as well as the points of ignition and rapid fire spread can be seen in both images. Amateur video footage of part of the event was taken from the point marked ‘Video’.

Fire crews were deployed at the scene within 15 minutes in order to contain the blaze. Over the next hour the fire managed to spread at a continuous pace, partly controlled by the firefighters, but at the end of that time a dramatic change in its behaviour took place. At about 8:15 am the flames advanced extremely rapidly over an area of nearly 6 hectares, completely overwhelming some of the fire crew; two young firefighters were killed and six others suffered burns, five of them severely. Survivors reported being surrounded by a *lake of fire* that rapidly developed and began to die away over a period of about one minute.

This chapter attempts to summarise the development of the fire that morning, highlighting the sudden and unusual change in its behaviour, drawing on available information (Raffalli et al., 2002 and Peuch, 2007) and on a field examination. It also makes use of an amateur video that partly captured the event, filmed from a vantage point beside the coastal road about 700 meters from the foot of the valley.

Figure 5.3. Views of the fire at approximately 7:15am (upper left), 7:30am (upper right) and a later image, as seen from different parts of the track.

The fire initially developed from the base of the north-western slope of the valley and spread steadily up the valley, encouraged by the slope and a moderate wind. As the top two views shown in Figure 5.3 demonstrate, the fire remained on just one side of the valley and spread relatively slowly during its initial period of growth. Nevertheless, at some stage, the lower flank of the fire reached and crossed the valley floor after which the fire developed more vigorously.

The third image in Figure 5.3, taken at a later time, shows that the fire had then spread much further up both sides of the valley. But what this picture also seems to show is that the head fire had been suppressed; in the photograph each flank fire comes to an end with no sign of any significant flames linking the two. This might have been seen as a positive development in bringing the fire under control. Subsequent events however demonstrated a highly unusual and, unfortunately, devastating form of fire spread.

Figure 5.4. Video images of the fire at about 8:15am spanning a total period of about one minute.

Visibility in the valley towards 8:15am, particularly in its upper reaches, was described as very poor, as a result of the smoke produced by the fire. Video images, taken from the point marked as 'Video' in Figure 5.2, corroborate this as seen in the first of the images in Figure 5.4. The remaining images in this figure show an extremely rapid development of the fire over a wide area of between 5 and 6 hectares, during a period of only one minute. The second image shows large flames, well exceeding the height of an electricity pylon. The remaining images show how a very rapid advancement of the fire left a widespread sheet of flame, simultaneously covering the entire upper reaches of the valley. This is what the survivors described as a lake of fire.

The *lake of fire* gradually faded away leaving a scorched landscape in which not everything seems to have been burnt. Even today, eight years after the incident, some fine dead fuel remains from the region of the lake of fire. Some leaves from the vegetation remain in place, apparently left unburnt but caramelised by the heat from the flames, as seen in Figure 5.5. The vegetation in the valley today (as seen in Figure 5.6) has not yet recovered to its level at the time of the fire (as seen in Figure 5.3).

It has been conjectured, for example by Peuch (2007), that the dramatic change in behaviour of the fire could have involved the spread of premixed flames, fuelled by unburnt pyrolysis gases, driven out of the vegetation lower down the slope, but remaining unburnt initially. As early as 1954, Arnold and Buck noted the existence of this kind of combustion in wildfires, some aspects of which were investigated by Rafalli et al (2002). An article by Dold et al (2005) and a New Scientist feature article by Williams (2007) also discussed the possibility that a similar phenomenon could have led to the very rapid spread of large flames over grazed out pastures, as witnessed by experienced firefighters during a large firestorm near Canberra in January 2003.

Figure 5.5. Caramelised leaves and fine vegetation still remaining 8 years after the fire.

Figure 5.6. A view, as it is today, from the part of the valley where the *lake of fire* formed in September 2000.

These gases would have consisted of many volatile organic compounds, some of which would condense into fine droplets at atmospheric temperatures forming a typically white or light grey smoke and reducing the visibility. In sufficiently high concentrations this pyrolysed fuel vapour would be able to support turbulent premixed flames, or deflagrations, that could propagate at several meters a second, readily being able to cover 200 meters in about a minute. The images seen in the video of the incident do appear to show flames spreading through the smoke above the vegetation at one stage.

This kind of flame spread through unburnt pyrolysis vapour is quite common in building fires where it contributes to what is known as *flashover*. It seems natural to use the same term in the context of open air vegetation fires when, as Arnold and Buck (1954) described it, a premixed "flame may *flash over* a considerable area" of mixed pyrolysis vapour and air.

If the mixture of pyrolysates and air contained an excess of fuel vapour over oxygen near ground level, then the premixed flames of the flashover would have left a diffusion flame in their wake, as described by Dold et al (2005). This would have taken the form of a sheet of flame above ground level, having little or no oxygen below it. Vegetation below this *lake of flame* would then have been heated by radiation from the flame above it but, in the absence of oxygen, would not have been able to burn directly. Such a flame would gradually have weakened in intensity as fuel and air would have mixed together more and more slowly, while still being cooled strongly through radiating away its energy. At some point, when heat losses exceeded the rate at which heat could be generated by the chemistry, the flame temperature would have dropped, in a phenomenon known as radiative quenching, causing the flame to cease burning. Fine vegetation near the ground would therefore have been subjected to strong heating for a while, in this case about a minute, but would not have been subjected to surface oxidation. Indeed the damage to the fire engines themselves also seems to have been relatively limited and the fire fighters within the engines were able to survive the flames.

It seems quite possible that the Palasca fire of September 2000 involved a flashover that covered up to six hectares of vegetation, although alternative explanations also need to be considered. Important questions remain as to why the fire might have burnt in this way. The separation of the fire into flanks with no head fire may have had a part in it; at this stage, the efforts of the firefighters might have succeeded in extinguishing the head fire, after which the flank fires should have been easier to tackle. On the other hand, it could have been the case that the extinction of the head was only partially successful: the flames might have been put out but the generation of pyrolysis gases that would otherwise have burnt in the head fire may have continued sufficiently strongly for a buildup to have developed into flammable proportions.

One problem with the idea of a *flashover* through the pyrolysis gases is that premixed flames can only propagate through relatively high concentrations of the combustible volatile organic compounds. Wildfires always produce such compounds but for them to support the propagation of premixed flames their concentration in air must exceed a certain flammability limit, the precise value of which is not known at this time although a crude estimate based on oxygen calorimetry of a typical carbohydrate $(CH_2O)_n$ and an estimated minimum self-sustaining flame temperature of about 900 Celsius would be approximately 6% by mass in air, representing the *lower flammability limit*. This is a fairly high concentration that would probably have been perceived as dense white or grey smoke and which would also have been likely to make normal breathing difficult. Volatile organic compounds at concentrations significantly below this level would present no danger from premixed flame propagation, or flashover.

For a flashover to have covered such a large region there should have been a buildup of combustible volatile organic compounds above the lower flammability limit over much of the area. This buildup need not have been particularly thick and would almost certainly not have been uniform over the region where the flashover spread. Variations in the thickness of the flammable region and in the concentration above the flammability limit would affect the propagation speed of the premixed flame, which may well have fluctuated significantly as the flashover moved relatively rapidly over the vegetation. The overall effect, however, would have been to achieve a rapid flame spread over the area of the flashover.

The stoichiometric concentration of carbohydrate pyrolysates of the form $(CH_2O)_n$ is about 18% by mass in air; at more than this concentration the fuel vapour and air mixture is rich, while at lesser values the mixture is lean. For a gaseous diffusion flame to be left in the wake of the propagating premixed flame of the flashover, the concentration of pyrolysis vapours would have needed to exceed this level, at least close enough to the vegetation. On the other hand, pyrolysis that is initiated by heating through the passage of the flashover could itself have initiated the widespread diffusion flame (the *lake of fire*) so that concentrations that may have been initially lower than the stoichiometric level might still have led to the generation of the lake of fire. Whatever the means by which it was established, this pyrolysis would then have kept the lake of fire refreshed with fuel vapour from below until radiative quenching set in.

An alternative explanation for the change in behaviour of the Palasca fire might be the development of an eruptive fire, as a continuous upslope acceleration of a fireline, as can be seen in other cases reported in this volume. These forms of eruptive fire can also be extremely destructive, developing into rapid rates of spread up slopes or in canyon-shaped topographies.

Eruptive fires were studied in the groundbreaking work of Viegas and Pita (2004) using a sloping canyon-shaped table in a laboratory; a full scale field experiment in a real canyon was also carried out. Viegas (2005, 2006) provided an insightful formulation that can model how an eruptive fire accelerates. More recently, articles by Dold et al (2009) have looked more deeply into the underlying physical mechanisms, arguing that any growth in fireline intensity is mainly due to an accumulation of flame depth, while different forms of feedback from intensity into spread rate lead to either steady or eruptive fire behaviour. Backed up by experimental observations, attachment of the air flow at the fireline, and especially ahead of it, was identified as a key factor that is likely to generate conditions for eruptive fire growth.

This is a feature of the air flow that could be developed into a possible warning sign for firefighters: if the air immediately ahead of a fire, that is spreading up a slope, is blowing uphill away from the fireline, rather than downslope towards it, then a potentially very dangerous situation may have developed.

According to these models and experimental investigations, both the intensity of the flames and their spread rate grow larger and larger, as a continuous fireline in an erupting fire, although there is not an abrupt change in spread rate as there would be for a flashover. It is feasible that the head fire of the blaze in Palasca may have reformed itself and developed very rapidly into an erupting fire with accelerating spread rates and flames of rapidly growing intensity.

The apparent quenching of the head fire in the Palasca incident does suggest that the fire might not have developed as a continuous fireline but as a form of premixed flame spread or flashover. Without deeper investigation, it is impossible to say with absolute certainty which form of rapid fire spread was involved. It may even be possible that a fire eruption of more devastating proportions could have arisen if the head fire had been able to continue unhindered.

Perhaps the most important lesson that should be drawn from the tragic fire of 17th September 2000 is that current practical and scientific knowledge of very dangerous forms of fire behaviour is limited. This is especially true when fires grow rapidly with no external driving force to alter the behaviour of the fire, as in the case of the Palasca fire. Moreover, until the hazards are widely recognised, firefighters will continue inadvertently to place themselves at risk.

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6. The fatal fire entrapment of Artemida (Greece) 2007

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Abstract

The fire season of 2007 in Greece was the worst in recent history as it set new records in regard to damages and loss of life. More than 270,000 hectares of vegetation burned and more than 110 villages were affected directly by the fire fronts. More than 3000 homes were totally or partially destroyed. Most important, a total of seventy eight (78) people, mostly civilians, lost their lives in a series of fire related accidents. The worst of these accidents involved entrapment of three seasonal fire fighters and a large group of civilians fleeing the fire near the village of Artemida in Ilia that resulted in the death of twenty three (23) people. This manuscript describes this tragic event and discusses the factors that led to the disaster.

Introduction

The fire season of 2007 in Greece was the worst in recent history as it set new records in regard to damages and loss of life. More than 270,000 hectares of vegetation burned and more than 110 villages were affected directly by the fire fronts. More than 3000 homes were totally or partially destroyed. Most important, a total of seventy eight (78) people, mostly civilians, lost their lives in a series of fire related accidents. The worst of these accidents was the fatal entrapment of three seasonal fire fighters and a large group of civilians fleeing the fire near the village of Artemida in Ilia. The aim of this chapter is to describe the events that led to the accident and to identify the factors that contributed to the disaster.

The general conditions

The fire season of 2007 was a difficult one for Greece. Winter was overall deficient in snowfall. Spring brought some rain but it was followed by a completely dry summer in the south of the country. The last days of June and of July respectively were characterized by two heat waves that had caused serious forest fire problems. The number of fires was higher than usual, but most important, fire behaviour was very aggressive. The Hellenic Fire Brigades (HFB) did not cope well with these difficulties. By the middle of August there had already been very heavy damages due to fires, including the destruction of Mount Parnis National Park near Athens, a 30,000 ha fire in Aigialia, Peloponnese and a 900 ha fire on mount Penteli Mountain that affected the northern suburbs of Athens. The disasters were reported extensively by the mass media. The publicity was higher than usual due to the size of the burned areas, the proximity of many fires to towns and settlements and, most important, the death of a number of firefighters, pilots and civilians in June and July. By August, the fires had become a source of serious concern and anxiety for the public.

A third heat wave hit the south part of the country on August 22 and 23. Air temperature reached 40 ^{o}C in many places and relative humidity dropped to very low levels. A fire on mount Parnon and a second one on mount Taygetos in south Peloponnese that both started on August 23, could not be controlled on that day.

Fire danger for Friday, August 24, was predicted by the General Secretariat for Civil Protection to be very high in Peloponnese because the meteorological forecast was for very strong winds in addition to the drought and the high temperature – low relative humidity combination. A new fire in the morning of Friday erupted near the towns of Oitylo and Areopolis, roughly 30 km south of the fire of Taygetos. Within hours it burned a large area and claimed six lives. It attracted immediately the attention of the HFB and the media until in the afternoon the news about the fatal accident near the village of Artemida in Ilia, Peloponnese, started coming.

Figure 6.1. Map of the general area of the fire from a 1:250000 scale map.

The accident near Artemida

The accident of Artemida was caused by a fire that started at about 14:40, August 24, 2007, in the yard of a house in the small settlement of Paleohori (Figure 6.1). It was started by an old woman cooking on an open stove and was reported immediately to the HFB as a house fire. However, as the fire caught on the vegetation close to the house it started accelerating and moving in a southwest direction fanned by a strong wind. Field weather measurements in the general area showed that temperature was at 40 oC, relative humidity varied between 10% and 17% , and the wind was blowing from a north-east direction at 12 km/h, with gusts reaching 29 km/h (Athanasiou, 2008). According to the account of the pilots of two Canadair water bombers that were flying in the area, they spotted the fire in its early stages as they were flying for another mission. They turned on it and made two water drops but they could not extinguish it completely. Then they flew to the sea to scoop more water. When they returned, about ten minutes later, they faced a fire perimeter of more than 1000 meters which they were unable to control.

Figure 6.2. Satellite view of the area between Paleohori and the accident site, showing the vegetation mosaic.

The fire spread the fastest, in the direction of the wind, in the grasses under the olive trees in the valley between the villages of Makistos and Artemida (also known as Koumouthekras) on the north side and Chrisohori, Milia and Arini on the south. This was true even where the grasses had been mowed to the ground. Spotting played a significant role in this quick spread as the dry dead grass was a receptive bed for the burning firebrands. As the fire front moved with bursts, it exhibited an average rate of spread of roughly 5 km/h. Unburned patches of trees, shrubs and other vegetation burned a few minutes later behind the fast moving front. Simultaneously, the perimeter widened as the north flank of the fire moved upslope, sweeping the forest-covered south slope of mount Lapithas Mountain along the north side of the valley.

The first village reached by the fire, at about 14:55, was Makistos at a distance of 1.7 km from Paleohori. The people there were caught by surprise. All but a handful left the village in panic towards the nearby village of Artemida with the fire front running after them. The fire was spreading at an average speed of 5 km/h, enough to catch a walking man. An elderly brother and sister, unmarried and living together, trying to save their donkey, fled on foot. They died next to the road towards Artemida when they were overtaken by the fire front. However, the donkey survived. In the abandoned village most houses were destroyed or seriously damaged. Only 14 of the 60 homes did not suffer damages. Some of them were saved by the efforts of those who stayed behind and fought to save their property.

The village of Artemida, was reached next by the fire at about 15:15. The people arriving from Makistos and most of the people of Artemida, in panic, fled the village in two groups. There is some information that local policemen were the ones who urged the people to leave. The first group formed a convoy of cars and moved towards the town of Zaharo. The second group, at the road intersection at the end of the village, chose to drive to higher ground, towards the village of Smerna. They probably realized that the quick spread of the fire in the valley would cut-off the route to Zaharo. This group as well as the people who stayed in the village survived without a problem.

Figure 6.3. Satellite view of the location of the accident.

The convoy driving towards Zaharo had to return as the road was cut by the fire. In the meantime a fire truck crewed by three seasonal fire fighters from the HFB had driven towards Arthemida but was unable to reach the village and returned towards Zaharo. This fire truck met the convoy of civilian cars returning to Arthemida and stopped at the place of the accident. An agricultural guard who was coming from the direction of Zaharo with his motorcycle joined the group. In the meantime the fire had nearly reached the road behind making any effort to return to the village a high-risk alternative. Having no option they stopped on the spot, in a bend of the road next to an olive grove (Figure 6.3), hoping that the firefighters that were with them would protect them. The grasses in the olive grove downslope from their location had not been cleared. There was also a clump of pine trees there. Grasses on the upslope side of the road had been mowed. The time was around 15:25. Immediately behind the agricultural guard, came the mayor of Zaharo driving his four wheel drive Jeep, having his first deputy-mayor with him. In the next approximately 5 minutes, the people in panic were seeing the fire coming uphill towards them. During these few minutes there were some phone calls, through mobile phones, both to the authorities and to friends and relatives. It is questionable if the authorities would be able to understand the pleas for help under those conditions, at least quickly enough to divert aerial means to make water drops. One of the persons who had remained in Artemida, a retired police officer, responded to the pleas for help of his sister who was with those trapped. He started to go there on foot hoping he would be able to help. He was later found dead on the road where he collapsed when the smoke and fire reached him.

As the fire was closing on the people from all sides, the mayor drove his Jeep on a narrow agricultural road surrounding the olive grove. At some point however the fire reached that spot and he had to abandon the vehicle returning to the asphalt road on foot. At that moment, coming from the direction of Artemida, the second deputy mayor arrived with another four wheel drive vehicle. The mayor jumped in the vehicle telling to the people that they had to leave by car through the flames. The first deputy mayor did not get into the car, determined to “stay and help the people”. Also, the mayor asked a lady who had her four children with her, to put the kids in the vehicle and run away but she refused to do so. Having no time to spare, he and the second deputy mayor drove through the flames in the direction of Artemida. They were able to escape unharmed.

The rest of the people who chose to stay on the asphalt road were certainly counting on the presence of the firefighters. Unfortunately, the three seasonal firefighters, probably because of the quick fire spread and the extreme fire behaviour on the slope (Figure 6.4), failed to operate their hose and fight the flames adequately although their truck was filled with water. When this became evident it was too late for the people to escape. Some stayed in their cars on the road. They did not survive. Most of the people fled from the road, running uphill in the olive grove. The fire caught some of them as they were running uphill including the mother with the four children. The rest of this group managed to make it to the top of the small hill, but on the other side they found themselves surrounded by fire from three sides. Eleven of them, including the agricultural guard, were trapped when they reached a small stand of pine trees on a steep rocky outcrop. They were found at the base of the rock close to each other.

Figure 6.4. Picture of the NW part of the front of the fire approximately 15 minutes after the accident, showing the extreme heat loads and the existence of heavy spotting and thick smoke.(Source: An amateur video uploaded on www.youtube.com)

The first deputy mayor and an immigrant worker were able to by pass this obstacle. They reached an open space immediately after the pines with few olive trees, cleared from most grasses. Unable to continue running due to the smoke and heat they fell on the ground and tried to protect themselves by covering their bodies with soil. As they were wearing shorts they received burns on their exposed skin from the burning embers that fell massively on them. However, after the passage of the fire they communicated by mobile phone with a friend asking for help. They were able to walk back to the road where their friend picked them with his car and took them to the hospital. The worker survived but the burns of the deputy mayor were infected and unexpectedly he died 28 days later in a hospital in Athens.

One more person, a young athletic man initially managed to outrun the fire. Immediately after the accident he was reported missing but his body was not found on the site. Unfortunately, he was found two days later, in a rock crevice where he had tried to protect himself from the heat two kilometres away from the accident scene. Obviously he had been running all this distance, mainly uphill towards the village of Smerna, chased by the fire from behind and was probably finally trapped by the north flank of the fire that was spreading along the slope of Lapithas mountain.

One young man and his mother who had stayed in their car on the road, realizing, when the tyres caught on fire, that they would not survive if they stayed there, decided to act. They drove through the flames towards Zaharo and survived.

Discussion and conclusions

The total number of victims reached twenty three (23), including the three firefighters. The first deputy mayor was the 24th victim. It was the worst accident of this type that ever happened in Greece. Studying the evolution of the event, the following contributing factors to the disaster can be identified:

The extreme weather conditions that led to a fire behaviour that the people did not anticipate.

The incomplete preparation of the olive groves in regard to grass treatment. In most such fields the grass had been mowed but was left on the site. Under this treatment, a large bunch of grass remains at the base of each olive tree, in an effort not to “injure” the tree. Under the extreme weather conditions, flying burning embers ignited massively the grass that was lying on the ground as well as the grass clumps at the base of the olive trees, starting them on fire.

The erroneous decision of the people to leave the village of Artemida. Those who stayed survived without risking their lives. Only seventeen (17) of the seventy (70) homes of the village were destroyed or heavily damaged.

The decision of the people to stay with the firefighters was not irrational. However it was unfortunate that the latter were not able to operate their pump and hose to protect themselves and the people in those conditions. Panic and lack of long professional experience may have been a contributing factor. It is also quite clear that had very little time to act and they faced extreme fire behaviour. We may doubt if that single vehicle was sufficient to save such a large number of persons at that site.

The specific location where the people stopped, at a bend of the road, contributed to the disaster. Although it was a relatively swallow draw, it did channel hot gasses. In these topography conditions fire erupted uphill with increasing intensity. Furthermore, at a distance of thirty meters from where they stopped, there was a group of tall pine trees among the olive trees. When these pines ignited the flames were tens of meters long and the radiation received by the firefighter crew at a distance of 30 meters was not tolerable. This may explain their failure to use the water in their truck. It may also explain why one or more cars on the road ignited, finally burning all of the other cars and killing the people in them.

It is notable that people who drove off the site, even at the last moment, both in the direction of Zaharo and towards Artemida, made it to safety. On the other hand, making a delayed decision to outrun the fire on foot when the firefighters failed to offer protection was probably the worst option. The strategy of the first deputy mayor and the immigrant worker to lie on the ground in an open space with little fuel and cover them with soil was, under the conditions, an effective one, even if by coincidence the former finally lost his life.

The lessons that can be learned from this accident are related to the mistakes that were made and the need to avoid repeating them in the future. They can be summarized as follows:

- Evacuation of settlements in case of forest fires is not necessarily a good option. However, when an evacuation is done spontaneously, without planning, the results can be catastrophic especially if realized at the last moment.
- The best option seems to remain in the houses at least as far as possible. This is especially true for the majority of homes in Greece and the rest of the

Mediterranean region which are generally not built with flammable materials. There are no reports of lives lost for citizens that remained in their homes.

- Vegetation treatment for fire hazard reduction is a wise measure, especially close to settlements. Citizens as well as the state may find themselves in much better and safer condition in case of an extreme fire event such as the one experienced in Peloponnese in August 2007.
- The people in fire prone countries need to be educated about forest fires, about the need and measures to prevent them, the risks they pose and the ways to protect themselves and their property.
- Firefighter safety training should be a priority for both professional and seasonal firefighters.

It can only be hoped that these lessons will be taken seriously into consideration in Greece and in other countries that face similar problems with forest fires. The extreme weather events that all countries experience as a result of the changing climate should make everyone take the risks posed by forest fires much more seriously than has been the case until now. Otherwise, this tragic event may soon be repeated in some other part of the world.

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Abstract
Forest fires can cause injuries and death to fire fighters and to population affected by them. The analysis of these accidents can provide a better insight about their causes and circumstances and develop guidelines to improve safety of all those at the fire line. These events are also a challenge for researchers as we try to better understand how fire and people behave and with this knowledge contribute to avoid these accidents. Some recent cases involving fatal accidents in five different countries are described and analyzed in this book. Common elements among them are the fact that both several fatalities and fire eruptions occurred in all of them. The number of victims ranges from two in Palasca (France) accident to 27 in Arthemida (Greece) case and they include professional and well experienced fire fighters and members of the population, in some cases even children. May these cases be a reminder that every person can be endangered by forest fires and a call to enforce the common goal of preventing them.

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