Integration of Scientific Research Results in Forest Fire Management

D.X. Viegas
Centro de Estudos sobre Incêndios Florestais - Associação para o Desenvolvimento da Aerodinâmica Industrial, University of Coimbra Coimbra, Portugal

Abstract

The complexity of forest fire problems does not allow an *ad hoc* and purely empirical approach to manage them in the long term. Complementing the learning process that is associated to the operational management of forest fires the scientific community has tried to develop a systematic body of knowledge about the various components of fire management. Applied research in forest fires is now practiced by a large community of scientists incorporating specialists from various fields that are spread in the entire World. The process of transferring the results of scientific research into operations and policies is not always easy. In the past history of learning lessons from forest fires with the help of science there are successes and drawbacks. A reflection on this topic is presented with the objective of finding future opportunities and additional motivation to improve this situation. Based on the experience of the author some situations of application of research findings and developments into fire management mainly in Europe and in Portugal are presented. One of the cases described is the generalised adoption of the Canadian Fire Weather Danger System as a standard by most European countries as a result of a comparative study carried out in the scope of a research project. The use of remote sensing to map burned areas and to assess vegetation status is one other example. The integrated use of video and infra-red cameras to detect and monitor wildfires and fire behaviour systems to support decision was also implemented. Fire behaviour studies related to fire safety issues are also mentioned.

Introduction

Forest fires are a very complex problem that challenges various parts of society to manage them and to prevent their undesired effects. As in many other fields of human activity scientific research has contributed to obtain a better insight on its general factors and long term trends. In spite of the dissemination of the results and achievements of the research community sometimes there is still a gap between the operational practice and the application of those findings. This situation is more evident in some parts of the World and in some countries than in others.

Until quite recently scientific research applied to forest fires in Europe was very dispersed and did not have common objectives. During the past twenty years with the support and guidance of the European Commission through several programs a scientific community was built in Europe and the involvement of end users in the application of scientific results is increasing continuously.

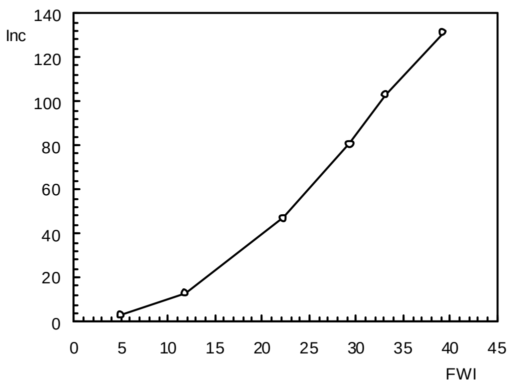
Given the very large number of research projects and other actions that have been carried out during these years it is not possible to make justice to all the achievements and results that have found successful application in forest fire management and policy in Europe.

An overview of the contributions given by the author and his research team with the support of other institutions for the integration of scientific research in forest fire management practice is given. The adoption of a common method to estimate meteorological fire danger was proposed. Based on systematic field measurements estimators of the dead and live fine fuel moisture content using meteorological parameters were calibrated. The importance of convective effects induced by the fire super imposed to ambient wind or terrain slope on fire spread was analysed systematically in laboratory experiments. An interpretation of the blow up effect that occurs very seldom in canyons and steep slopes is proposed. Application of advanced technologies such as electronic devices to detect and monitor fires and unmanned aerial vehicles to support fire management is addressed.

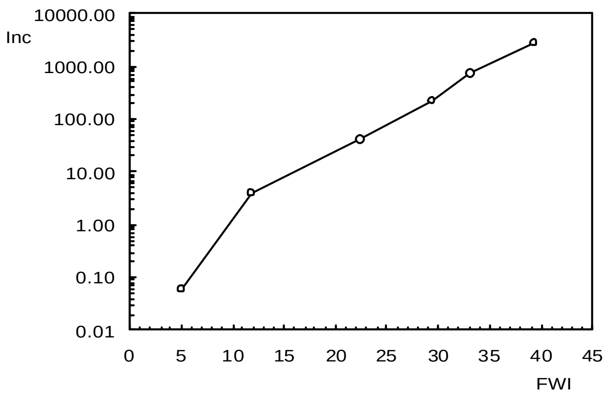
Fire Danger Prediction

In recognition of the great importance of meteorological factors to forest fire occurrence and propagation several methods have been developed in various parts of the World with the purpose of capturing in a simple formula or in a complex system of equations the contribution of those factors expressing it in a category or class of fire danger related to meteorology. The author coordinated a comparative study of various fire danger systems to fire prone regions in three different countries of Southern Europe: Portugal, France and Italy (Viegas *et al.* 1999). Five methods were considered in the study: the Portuguese modified Nesterov system; (ii) the Spanish ICONA system; (iii) the French SOL system; (iv) the IREPI Italian System and (v) the Canadian Fire Weather Index (FWI). Using daily values of meteorological parameters from representative stations during the fire season for each region and statistical data on fire occurrence (number of fires and burned are per day) in a period of five to ten years the capacity of each system to estimate fire danger was assessed. Using statistical methods and different criteria to assess fire danger estimation an objective assessment of the relative performance of each method was made. It was found that in practically all cases the FWI had a better performance than all the others, even for those regions for which some of the systems had been purposely developed.

As a consequence of this study it was recommended that the Canadian FWI should be adopted as a standard method to estimate fire danger related to meteorological conditions. This recommendation was followed in France and in Portugal with very good results (Fig. 1) and other countries are considering its implementation as well.



(a)



(b)

Figure 1 – Relationship between daily values of FWI and the average number of fires (a) and burned area (b) in the District of Coimbra from 1988 to 1992.

Fuel status estimation

Moisture content of fuel particles is a major factor affecting the flammability and combustibility of forest fuels therefore the capacity to estimate its value from other related parameters is of great importance in the fire behaviour prediction process.

The Canadian FDRS has a set of intermediate outputs that are related to the moisture content of various strata of forest fuels. The Fine Fuel Moisture Code (FFMC) is related to the moisture content of fine particles of dead fuels. In spite of the physical basis of its development its application to specific fuels of a given region require calibration. In Portugal we have a data set of daily values of fuel moisture content of six different fuel particles and the corresponding set of meteorological data for a period of several years. Using these data it was possible to produce a specific calibration of FFMC as an estimator of moisture content of fuels that are commonly found in Portuguese forests. As an example the case of dead particles of *Pinus pinaster* is shown in Figure 2.

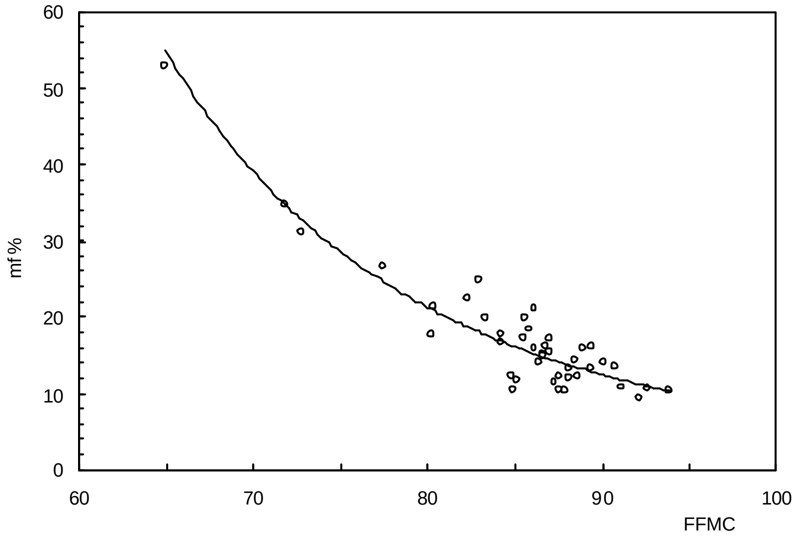


Figure 2 – Relationship between FFMC and the average value of moisture content of dead leaves of *Pinus pinaster* at Lousã (District of Coimbra) from 1994 to 1996.

One other intermediate output of the Canadian System is the Drought Code (DC) that is in principle an estimator of the dryness of the soil. In a study carried out by Viegas *et al* (2001) it was demonstrated that DC is also a good estimator of moisture content of live shrubs during the fire season. As an example the results obtained with *Calluna vulgaris* are shown in Figure 3.

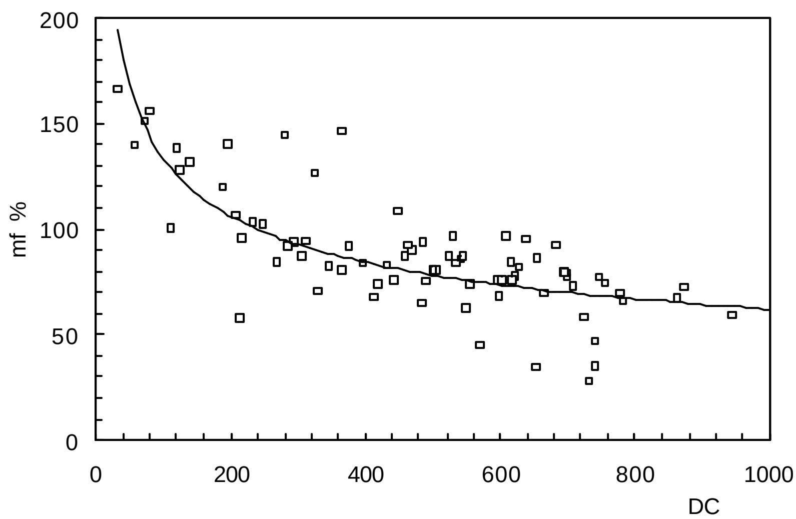


Figure 3– Relationship between DC and the average value of moisture content of leaves of *Calluna vulgaris* at Lousã (District of Coimbra) from 1994 to 1996.

Slope and Wind Effects on Fire Spread

Slope and wind are widely recognized as two of the most relevant factors in fire behaviour. Their role is quite complex even when acting isolated – which rarely happens – but when both are present the processes are even less understood. For this reason the author has dedicated much of his effort in the research on this very challenging problem.

Using theoretical concepts, physical interpretations or prediction models were developed to explain some of the phenomena that are observed during fire spread under slope or wind action. This analysis was supported on a comprehensive experimental research carried out in the Forest Fire Laboratory that was created in Portugal under his supervision and also in field experiments (Viegas *et al.* 2002*c*).

One of the outcomes of this observations and research was the finding that for a given set of boundary conditions, in the general case, there is not only a single value of the rate of spread. This result is in contradiction to the common assumption that once we have the pertinent fuel bed properties and ambient conditions it is possible to estimate the ROS of the fire front. An example of this philosophy is the Rothermel model (Rothermel 1972) that allows to determine the ROS of a fire in practically all conditions.

The analysis of the evolution of a fire line in a slope was used to illustrate this concept. According to the previous models the rate of spread should be the same at all points of this fire line as the only governing factor is terrain slope that is uniform along the entire fuel bed. It is observed that on the contrary some parts of the fire front spread faster than others confirming that in this very simple and common situation there is not a unique value of the rate of spread. As the rate of spread is not constant along the fire front its movement is composed by a translation and a rotation. In order to interpret this rotation movement the author analysed the convective flow that is induced by the fire front and its interaction with the combustion reaction itself. It was demonstrated that these convective currents induced by the fire are responsible for the continuous modification of fire behaviour properties.

This phenomenon was put in evidence again in the original research carried out by the author and his co-workers on the joint effect of slope and wind on the development of a point source fire (Viegas *et al.* 2002*a*). A special device was designed and built to allow the systematic study of this effect for arbitrary wind intensity and direction and slope inclination (Fig. 4). It was found that the contour of the fire is not symmetrical and its shape is changing continuously. It was observed that different sections of the fire line are subject to different convective effects: (i) favourable wind and slope effects; (ii) favourable wind and contrary slope; (iii) contrary wind and favourable slope and (iv) contrary wind and contrary slope. It was found that a vector sum of slope and wind effects, as proposed by Rothermel (1983) gives a good approximation of the dominating convective effects at each section of the fire front.

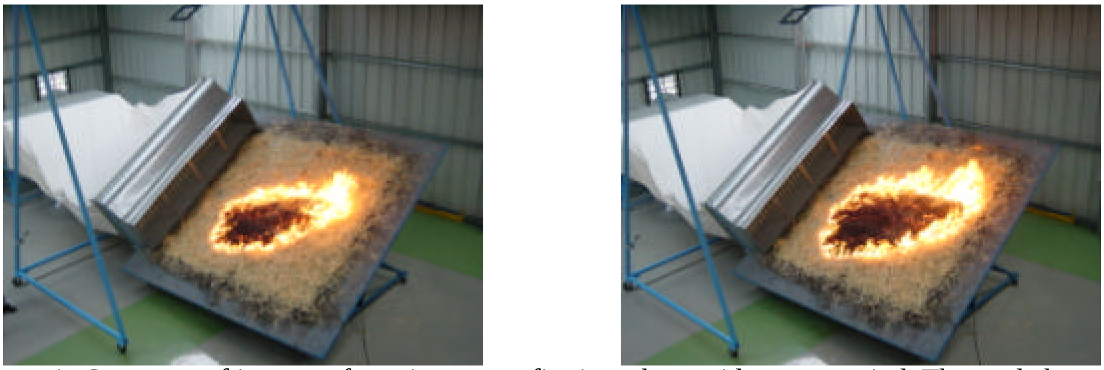


Figure 4– Sequence of images of a point source fire in a slope with a cross-wind. The angle between wind direction and slope gradient is 90º.

Fire spread in canyons and blow-ups

Canyons are commonly associated to a very rapid fire spread that is designated as "blow-up" or "flare up" in the literature. Many fatal accidents that occurred in the past are associated to such behaviour and to canyon fire spread or to very steep slopes. Mann Gulch (Rothermel 1990), South Canyon (Butler *et al.* 1996) and Thirtymile (Furnish *et al.* 2001) fire accidents are just some examples of such accidents.

Attention to fires in canyons started in our team with the experimental flow analysis and numerical flow and fire spread simulation developed by Lopes *et al.* (1995). A field experiment in a canyon was carried out in 2001 by our team and is reported in Viegas and Pita (2002). A laboratory experimental program was started in an original device designed and built for this purpose in 2002. Details on this study are given also in Viegas and Pita (2002).

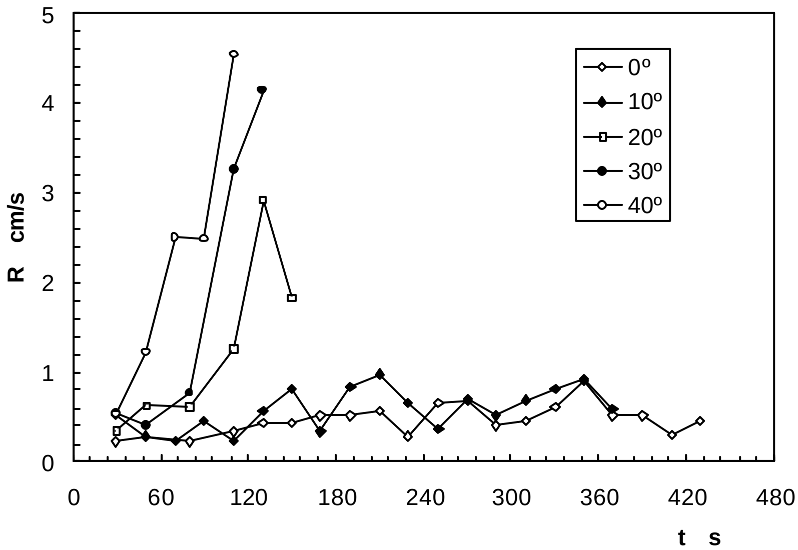


Figure 5– Rate of spread of head fire in canyons measured in the laboratory (δ=40º; values of α indicated in the figure).

These experiments put in evidence that the occurrence of blow-up depends on the fuel bed and terrain configuration properties. Even at the laboratory scale ($3x3m^2$) blow up occurred whenever the inclination angles were greater than 20º (Fig.5). It was concluded that no special atmospheric phenomena had to exist in order to justify the occurrence of blow-up.

Based on these observations an analytical model was developed to describe the interaction between the fire and the atmospheric wind. This model is under development but shows good potential to explain the blow-up effect.

Decision support systems

In order to promote the transfer of the findings of scientific research and the introduction of new technologies in fire management and suppression operations several pilot actions have been carried out in Portugal by our team in close cooperation with the operational institutions.

An operational test of fire detection systems using video and infra-red cameras and different image and data transmission methods was performed in Central Portugal from 2000 to 2002 in the Eagle Project (Viegas *et al.* 2002*b*). Five different systems were installed at four sites that were operated from a coordination Centre covering an area of around 1500 km^2. The capacity to detect fires automatically that some of the systems installed had was fully demonstrated. The possibility of monitoring fires continuously and to use the images to support the decision making process was greatly appreciated by the fire suppression coordinators.

(a) (b)

Figure 6 – Two of the fire detection systems tested in the scope of Eagle project: a) BSDS system; b) Bosque system.

A fire simulator *Firestation®* developed by Lopes *et al.* (2002) was employed in this support as well. Integrating wind, terrain and fuel data the system estimates the propagation of the fire during the next few hours and allows the analysis of different fire suppression tactics.

In an ongoing project COMETS the use of unmanned aerial vehicles (UAVs) in forest fire management activities is being tested. In a field campaign that was carried out in Portugal in May two helicopters and one blimp were flown simultaneously in the vicinity of an experimental fire and their capacity to acquire and transmit images and data in real time to a field command post was demonstrated successfully.

Conclusion

Based on the experience of the author some situations of application of research findings and developments into fire management mainly in Europe and in Portugal are presented.

One of the cases described is the generalised adoption of the Canadian Fire Weather Danger System as a standard by most European countries as a result of a comparative study carried out in the scope of a research project. The use of remote sensing to map burned areas and to assess vegetation status is one other example. The integrated use of video and infra-red cameras to detect and monitor wildfires and fire behaviour systems to support decision was also implemented. Fire behaviour studies related to fire safety issues are also mentioned.

Acknowledgements

The author wishes to thank to all his colleagues of the ADAI team for their help in the performance of the research activity that contributed to the realisation of the activities and to the creation of the body of knowledge that was described in this paper. The present research is included in the program of project WINSLOPE (Contract POCTI/34128/EME/2000) supported by *Fundação para a Ciência e Tecnologia*, and projects COMETS (Contract IST-2001-34304) and SPREAD (Contract EVG1-CT2001-00043) supported by the European Commission. This research was performed in close cooperation and with the support of several Portuguese institutions in particular from the Forest Service, the Institute of Meteorology and the Fire Brigade Service. This support is also gratefully acknowledged.

References

Butler, B.W., R.A. Bartlette, L.S. Bradshaw, J.D. Cohen, P.L. Andrews, T. Putnam and R.J. Mangan, 1998. Fire behaviour associated with the 1994 South Canyon Fire on Storm King Mountain, Colorado, USDA Forest Service Res. Pap. RMRS-RP-9.1998.

Furnish, J., A. Chockie, L. Anderson, K. Connaughton, D. Dash, J. Duran, B. Graham, G. Jackson, T. Kern, R. Lasko, J. Prange, J. Pincha-Tulley and C. Withlock, 2001. Thirtymile Fire Investigation. Factual Report and Management Evaluation Report. USDA, Forest Service, September 2001.

Lopes A.G., C.M. Sousa and D.X. Viegas, 1995. Numerical simulation of turbulent flow and fire propagation in complex topography. *Numerical Heat Transfer Journal*, 1995, Part A, nº27, pp. 229-253.

Lopes A.M., M.G. Cruz and D.X. Viegas, 2002. *FireStation* - an integrated software system for the numerical simulation of fire spread on complex topography. *Environmental Modelling & Software* 17, 269-285

Rothermel, R.C., 1972. A mathematical model for predicting fire spread in wildland fuels. USDA, Forest Service, Research Paper, INT -115.

Rothermel, R.C., 1983. How to predict the spread and intensity of forest and range fires. USDA, Forest Service, Gen. Tech. Rep. INT-143.

Rothermel, R.C., 1993. Mann Gulch Fire: A Race that Couldn't be Won. USDA Intermountain Research Station, General Technical Report INT-299

Viegas, D.X., G. Bovio, A. Ferreira, A. Nosenzo and B. Sol, 1999. Comparative study of various methods of fire danger evaluation in southern Europe. *International Journal of Wildland Fire* 9, 235-246.

Viegas, D.X., J. Piñol, M.T. Viegas and R. Ogaya, 2001. Estimating live fine fuels moisture content using meteorologically-based indices. *International Journal of Wildland Fire* 10, 223-240.

Viegas, D.X., L.P. Pita, 2002. Fire spread in Canyons. Lecture Notes given at the IV Short Course on Fire Behaviour Modeling, Luso, 23-24 November.

Viegas, D.X., L.P. Pita, L. Matos, and P. Palheiro, 2002*a*. Slope and wind effects on fire spread. *In*: Proceedings of the 4th International Conference on Forest Fire Research and Wildland Fire Safety, D.X. Viegas (ed.), Luso, Portugal, November, 18 - 23, Millpress Science Publishers, Rotterdam, Netherlands.

Viegas, D.X., L.M. Ribeiro, B. Fernando and A.J. Silva, 2002*b*. A Pilot experiment of application of advanced fire detection systems to support fire management. Project Eagle. *In*: Proceedings of the 4th International Conference on Forest Fire Research and

Wildland Fire Safety, D.X. Viegas (ed.), Luso, Portugal, November, 18 - 23, Millpress Science Publishers, Rotterdam, Netherlands.

Viegas, D.X., M.G. Cruz, L.M. Ribeiro, A.J. Silva, A. Ollero, B. Arrue, R. Dios, F. Gómez-Rodríguez, L. Merino, A. I. Miranda and P. Santos, 2002*c*. Gestosa Fire Spread Experiments. *In:* Proceedings of the 4th International Conference on Forest Fire Research and Wildland Fire Safety, D.X. Viegas (ed.), Luso, Portugal, November, 18 - 23, Millpress Science Publishers, Rotterdam, Netherlands.