METEOROLOGY AS AN AID IN FIGHTING AND PREVENTING FOREST FIRES

By Bernard Sol; Météo-France, Bureau Etudes et Développement, Direction interrégionale sud-est

ABSTRACT

Techniques already exist for estimating the meteorological risk of forest fire. These take the form of indices based on measurements and forecasts of meteorological parameters and, for certain types of vegetation, on remote sensing. Provision of such information to forest fire agencies requires only modest technical efforts by meteorological services, where effective and reliable meteorological observation networks exist. Close cooperation between meteorological services and agencies established to prevent and fight fire is the key to effective fire prevention and response.

1. INTRODUCTION

No region of the world is unaffected by forest fires. Forests were catching fire even before humans appeared on the scene and nature took its time in restoring the plant cover. These fires were mainly caused by lightning and must have affected enormous areas. Nowadays, however, most fires are started by human activities, though lightning is still the primary cause in some regions. Fire is, for example, one of the techniques used to promote the growth of crops or pastures. Under controlled conditions, it can also be used in forest management though, sadly, it is sometimes used for other purposes.

Reducing the overall number of forest fire outbreaks is a non-meteorological challenge and is, consequently, beyond the scope of the present discussion. This presentation focuses, instead, on techniques for determining the risk of a fire spreading. The paper begins with an overview of the theory relating to the spread of forest fires. This is followed by a description of the physical phenomena involved, in order to distinguish clearly between the various methods that apply to different types of plant cover and climate. Finally, operational techniques are discussed which can help meteorological services to establish effective cooperation with fire prevention and fire fighting agencies.

2. SPREADING OF FIRES

The following three components are needed if a fire is to spread (Trabaud, 1989):

- Fuel (plant cover), which must be sufficiently dry;
- Oxygen (supplied by the wind), to promote combustion;
- A local heat source (lightning, match, etc.), to act as a catalyst.

2.1 LAYERS OF PLANT COVER

Generally speaking, plant cover can be divided into a number of layers based on the height of the plants concerned:

- A litter layer made up of dead plant debris at ground level;
- A herbaceous layer comprising herbaceous plants whose state depends on climatic conditions since their roots draw water only from the surface layer. Such plants are green during wet periods and when in active growth but dry out where they stand after reaching maturity and during dry periods;
- A shrub layer composed of plants which contain a greater amount of inflammable material and do not dry out completely. They can grow to a height of a few metres;
- An arboreal layer made up of trees

In some regions (e.g. large forests), a layer of humus (i.e. decomposed plant material lying under the litter layer) must also be taken into account as it can be an important vector in the spread of fires. The physical processes governing the spread of ground fires are peculiar to such fires. These spread slowly, give off little smoke, are very difficult to extinguish and often follow surface fires.

In certain forms of plant cover, some of the above layers may be missing. For example, there is no litter layer in arid steppe areas and no shrub layer in savanna areas

2.2 PROCESSES GOVERNING THE SPREAD OF A SURFACE FIRE

Plants burn in two stages:

- Pyrolysis. the plant loses its water through evaporation caused by heat supplied by the burning of neighbouring plants or by ignition. This is the "endothermic" stage.
- Combustion: This is the "exothermic" stage.

SPREAD OF A FOREST FIRE

Arboreal layer

Burning fragments are projected ahead of the fire

Shrub layer

Herbaceous layer

Litter layer

Fire can only spread if the heat generated during combustion is greater than that absorbed during pyrolysis. Hence, no combustion can take place when plants are very green (i.e. have high water content). Fire starts in the litter layer, which is generally dry enough to ignite unless there has been early morning dew or recent rain. The burning litter then generates the heat needed to cause pyrolysis of the herbaceous layer. Provided that this layer is not too wet, it will then ignite and cause pyrolysis in the shrub layer. This, in turn, leads to ignition in the arboreal layer, if one is present. Burning fragments then fall to the ground, setting more of the litter layer on fire. Subsequently, the fire spreads at a rate which depends on the dryness of the vegetation, the wind speed, the air temperature and the structure of the plant cover.

3. ASSESSING THE FIRE RISK

Obviously, it will never be possible to foresee exactly where and when fires will break out and, in consequence, fire will remain an unpredictable hazard. Since much information is now available on periods and areas of greatest risk, however, outbreaks of fire can be anticipated, information can be made available to the populations concerned and preventive measures can even be taken. Different methods will be used to determine risk level, depending on the type of plant cover and climatic conditions.

No universal method for meteorological assessment of fire risk can be proposed as the best for all countries. A study carried out in four Mediterranean countries in Europe (south-eastern France, Greece, Italy and Portugal) (Viegas, Sol *et al*, 1994), for example, compared methods used for the meteorological assessment of fire risk. This study showed that the same method did not always give the best results even though the plant cover was of the same type (Mediterranean vegetation). Results depended on the country concerned and the type of fire (e.g. such as summer fires in flat country, winter fires, hill fires). Results also depend on whether the aim is to prevent a fire from breaking out or from spreading and becoming a major forest fire

WMO recently distributed a related questionnaire to the countries in its Regional Association VI (Europe). Analysis of the 31 responses received clearly reveals the diversity of methods used to assess the fire risk. Despite this caution, the following sections provide some guidance to assist countries with no experience in the field to take an effective approach to the problem and circumvent long periods of preliminary research.

3.1 TIME-SCALE CONSIDERATIONS

There should be a clear indication of the time-scale involved.

3.1.1 THE "CLIMATIC" SCALE

This entails a clear understanding of seasons of greatest fire risk, in climatological terms Here, the contribution made by the meteorological service will be linked to its knowledge of the climate and possible climatic variations, such as those caused by phenomena like El Niño. This knowledge facilitates the precise identification of high-risk periods so that effective information can be made available to prevent the outbreak of fires.

The climatic fire scale is governed by the phenological stages of the various layers of vegetation. Shrubs dormant in winter, for example, can be as likely to catch fire as plants suffering from water stress in summer while frost will increase the amount of dead, highly inflammable, vegetation. For this reason, knowledge of variations in plant phenology and their propensity for catching fire is a prerequisite to any study on the subject Such knowledge will, for example, prevent the identification of plants that are green and in full growth as being in a period of high risk. The danger index is often wrongly assessed during such periods.

3.1.2 The Short and Medium Scale

Forecasts of periods of high-risk, made several days in advance, can be of assistance in placing fire-fighting teams on maximum alert, gaining precious time in the event of fire and warning populations of potential danger. Forecasts of variations in the fire-risk level should be made on a daily basis in order to define the areas at greatest risk due to wind and dryness. Methods such as risk index, water balance calculations and remote sensing play an extremely useful role in such instances.

3.1.3 The Nowcasting Scale

This scale applies when a fire is in progress and calculations of the level of risk are no longer useful. The main task at this stage is to determine how the wind will affect the fire and its progress during the coming hours, in order to anticipate how the fire will spread. Provision of this type of assistance is a routine task for meteorological services. The challenge lies in quickly establishing effective and practicable links between fire-fighting teams and meteorological services.

3.2 OVERALL RISK/METEOROLOGICALLY ASSESSED RISK

Determination of the overall fire risk involves three types of factors:

- Operational components such as the availability of fire-fighting personnel, risk factors for the outbreak of fire and others. An understanding of farming, woodland and pastoral practices is included in this component and be must taken into account in any system of fire prevention;
- Condition of the plant cover; This component does not, strictly speaking, concern meteorological services; and
- Weather conditions.

GENERAL FIRE RISK

Operational Components	Condition of Plant Cover	Weather Conditions (Field of Action of a Meteorological Service)

3.3 CONDITION OF PLANT COVER

The condition of plant cover in relation to the outbreak and spread of fire, may be indicated by a number of parameters such as water content and flammability interval (i.e. time taken to catch fire). It is, however, extremely difficult to provide these indices in real time since *in situ* measurements are demanding (due to personnel requirements, difficult sampling techniques, plant destruction, plant representativity, etc.) and can only be applied to a restricted number of species in all the vegetation layers. Some countries measure the water content of the litter on a daily basis. However, this technique only provides information on the risk of the outbreak of fire from one day to the next and does not make it possible to forecast the fire-risk level several days in advance. The role played here by remote sensing is discussed later in this paper.

Due to the absence of any simple real-time means of ascertaining the condition of plant cover, meteorological assessment of risk has to take plant cover condition into account more or less directly This is why such assessments are included in the field of action of meteorological services.

We shall now turn to the meteorological assessment of fire risk, indirectly including the condition of the plant cover.

4 METEOROLOGICAL ASSESSMENT OF FIRE RISK

How can fire risk be assessed in meteorological terms? A number of approaches are possible:

- The conventional approach using indices calculated from meteorological measurements. These include simulations of the condition of plant cover;
- The mixed approach using plant cover measurements and weather forecasts;
- The remote-sensing approach where the condition of plant cover is determined from satellite measurements. This approach should be used in conjunction with weather forecasts.

It is important to note that the meaning of fire-risk indices has to be properly understood (i.e. do they imply risk of outbreak, risk of spread or both?).

4.1 THE CONVENTIONAL APPROACH: METEOROLOGICAL INDICES OF FIRE RISK

Numerous methods have been proposed for determining fire risk levels from meteorological measurements alone. In the study cited earlier, for example, Viegas and Sol identified over a dozen methods used in the Mediterranean region of Europe alone.

4.1.1 Parameters Required

All methods require virtually the same meteorological parameters:

- wind forecast;
- air temperature and humidity forecast;
- cloud cover forecast or, for some methods, radiation forecast;
- measurements of rainfall (accumulated over 24 hours), wind, temperature and sometimes humidity (at least minimum and maximum).

The simplest of these methods only require wind, temperature and humidity forecasts. Another method combines the wind-speed forecast with the water balance derived from measurements of precipitation and mean temperature. Still others require information on the number of days that have elapsed since the previous significant rainfall.

The observed parameters (rainfall, temperature, etc) are used to monitor soil moisture reservoirs (or Sub-Indices) which represent the amount of water available to the plant cover. The Canadian method (Van Wagner, 1987) uses three Sub-Indices for this purpose; one of very low inertia which relates to the water content in the litter and small, dead plants (important for the outbreak of fire) and two others known as the Dryness Index and the Humus Index, which relate to upper layers (important for the spread of fire). While these reservoirs (or sub-indices) are clearly less useful than measurements taken directly from the plant cover, they can be calculated from simple meteorological parameters. Generally speaking, the simplest methods – those based on the temperature and humidity of the litter cover and on wind speed – are used to calculate the risk of outbreaks of fire while methods that investigate the reservoirs are used to predict the spread of fire.

It is important to note that reliable and continuous measurements of meteorological parameters, taken every day throughout the year, are absolutely essential to the calculation of sub-indices. Any interruption in observations will break the calculation chain. Gaps in the information are, however, acceptable during some periods of the year such as the rainy season or the early part of the fire-risk season when reservoirs are saturated with water. The availability of real-time measurements will sometimes determine which method is to be used. If humidity measurements and forecasts are not available, for example, a method will have to be selected that does not rely on these measurements.

4.1.2 Location and Density of Meteorological Measurements

Meteorological measurements used in the calculation of sub-indices representing the condition of the plant cover need not necessarily be taken in woodland or among the plant cover under direct threat. Measurements taken nearby will serve perfectly well, even those from an airport site. It is essential, however, that the same meteorological stations be used each time so that the climatology of the Indices can be determined, Indices can be calibrated against fires and subsequent comparisons of risk levels can be undertaken on a daily or annual basis. In addition, measurements taken in woodland do not provide a good assessment of the wind, which is an essential component in the spread of fires.

The density of the observational network will depend on the variability of weather conditions in the area concerned. It will be greatest in the case of rainfall measurements. In south-eastern France, which is a very mountainous area, station density, for example, averages one every 500 km^2. The fine-tuning of forecasts in spatial terms is determined by network density. Expansion of the measurement network to improve assessment of fire risk will teach meteorologists to recognize and thus to forecast mesoscale phenomena.

4.1.3 Choice of Method

As explained earlier, the choice of method will depend on which meteorological components are available and there is no need to create a new method to suit each country. It is suggested, however, that the Canadian method, the Fire-Weather Index (Van Wagner, 1987), be tried first. Even though it was developed in Canadian forests, this method gave the most consistent results in Mediterranean plant cover (garrigue, maquis, broad-leaf and coniferous forest) during the comparative study mentioned earlier. Its only disadvantage is that it requires humidity measurements and forecasts and computer facilities.

4.2 THE MIXED APPROACH: PLANT COVER MEASUREMENTS AND WEATHER FORECASTS

This approach requires considerable infrastructure (Valette, 1994). Samples of litter or living plants are collected by forestry staff who then weigh and kiln them. Only then can these samples be used, in combination with meteorological measurements and weather forecasts, for the meteorological assessment of fire-risk. The quality of the sub-indices indicating the condition of the plant cover is necessarily of the same order as the accuracy and representativity of the samples.

The results obtained from the mixed approach are only valid for one day. Thus, its capability for advance warning is very limited. For this reason, we do not recommend this approach if a reliable network of meteorological measurements is available.

4.3 THE REMOTE-SENSING APPROACH

Many articles in the scientific literature outline the virtues of remote sensing for the prevention or forecasting of forest fires (Deshayes *et al*, 1998). This approach uses easily repeatable measurements for direct assessment of the condition of the plant cover. Satellite images provide information on a much smaller scale than meteorological or forestry measuring station networks. In addition, the cost of such images is insignificant so long as forecasters restrict themselves to images with a resolution in the order of $1km^2$, quite sufficient for the purpose at hand. Furthermore, satellites pass overhead frequently enough to take pictures at intervals that meet operational needs.

Current satellites make the Normalized Differential Vegetation Index (NDVI) and the surface temperature available for determining the water balance of plant cover. In theory, stress in the plant cover can be determined by the combination of these two products. The author, however, takes the somewhat more cautious view that any attempt to make generalizations covering all plant species should be avoided.

4.3.1 Forested Areas

Programmes currently in operation in Europe make use of remote sensing output. Satellites, however, largely see the upper surface of forest areas while the lower layers are the main vectors of fire and determine the ferocity of the blaze. Tracking temporal variations in the stress in plant cover during the main fire-risk season is currently more difficult by remote sensing than it is by using dryness sub-indices determined from meteorological observations. In the Mediterranean zone, for example, remote sensing clearly shows differences between the end of the spring growth period (i.e. the beginning of the fire season) and the period of maximum water stress (i.e. later summer, before the onset of the heavy autumnal rains). Fluctuations from one week to the next or during the period just before the rainy season are, however, difficult to track. On the other hand, remote sensing provides improved insight into the spatial distribution of the risk since the grid interval is well below that of any meteorological network. The task then is to incorporate remote sensing images in a Geographical Information System which also makes it possible to combine information on plant cover with operational components, relief, fire outbreaks and other data.

The latest satellite products, such as those from active on-board sensors that can penetrate masking cloud and the various vegetation layers, may shortly offer a new operational approach and related research is under way.

4.3.2 Prairies and Savanna

Remote sensing provides a clear indication of the onset of the fire-risk season for areas in which the herbaceous layer is the predominant plant cover (i.e. savanna), through a rapid and quite perceptible change in the vegetation index In this case, remote sensing data are more informative than any sub-index or soil moisture reservoir. The fire-risk season is thus clearly marked and it is possible to monitor the gradual geographical spread of areas likely to catch fire. In consequence, fire prevention campaigns can be targeted more accurately in both space and time. Furthermore, related indices, such as the Fire Outbreak Index associated with the wind forecast, can be safely applied to areas where the goal is, for example, to burn off grass. It is important to note here that remote sensing has been used for some time for agricultural activities such as monitoring crop growth and forecasting harvest dates.

4.3.3 Meteorological Assessment of Fire Risk

Even though remote sensing gives an improved indication of the water stress of plant cover, it must still be used in conjunction with weather forecasts to provide adequate warning to services responsible for fire fighting, fire prevention and informing the public. Traditional meteorological risk indices, familiar to the fire-fighting services of some countries, comprise a combination of meteorological forecasts and plant cover sub-indices. The goal now is to add the Normalized Differential Vegetation Index (NDVI), surface temperature, and any other parameters detected by remote sensing to these indices.

5. FIRES STARTED BY LIGHTNING

Fire-fighting services should be informed, in real time, of lightning strikes observed during periods when fires are likely (i.e. in terms of the meteorological fire-risk indices). Fire may break out some hours after a strike (after smouldering in the humus layer) even if the thunderstorm is not a dry one.

The parts of the world in which fires are started by lighting would do well to install networks for the detection of lightning strikes to ground, if such facilities are not already in place. Such detection networks would make it possible to dispatch fire-fighting teams to affected locations. A lightning strike detection network of this kind also has many other meteorological applications.

6. METEOROLOGICAL ASSISTANCE

As previously discussed, meteorological methods for forecasting fire-risk already exist, though some research may be required to adapt them to the meteorological and plant conditions prevailing in each country and to the measurement networks available. Like any other meteorological product, however, such forecasts are only useful when applied within an operational framework. The following sections address this aspect

6.1 COOPERATION AMONG SERVICES

A very close relationship and a high-level of trust must be established between the meteorological service and the agencies responsible for fire prevention and fire fighting. Meteorological services should work in cooperation with the forestry service when undertaking studies to determine the best method for determining fire-risk level. They should, as a minimum, obtain available fire statistics in order to gain insight into the problems facing the country such as the causes of fires, fire and vegetation types, phenological stages and seasons. They should, moreover, also ascertain whether fires are linked to climatic incidents such as El Niño events.

Having acquired knowledge of wind and rainfall patterns, meteorologists would then be in a position to upgrade observation networks in the area and to provide input for the calculation of indices. In some instances, the observation network can be upgraded by the forestry service itself. In other countries, the forestry service may choose to determine the fire-risk level using conventional meteorological forecasting parameters. Regardless of which approach is chosen, the essential point is that there should be complete cooperation with meteorological and fire-fighting services exchanging information whenever necessary. Meteorological assistance may even include making a forecaster available for the duration of a fire to provide direct assistance to the fire-fighting service. This form of assistance, which has been practiced in France for 20 years, generates a high level of mutual understanding, inspires an essential climate of trust and is also a highly economical way of operating for all services concerned (Sol, 1994). Moreover, it should not be forgotten that fire-risk forecasting only just falls within (and may even be beyond!) the scope of meteorological services. This provides a further reason why the agencies concerned, whether they are meteorological, forestry or fire-fighting services, must work in cooperation, as they have much to learn from one another.

6.1 PREVENTION

The best means of prevention generally entail keeping people informed, especially those who start fires for agricultural or pastoral purposes or who use the countryside for recreational activities.

Such information should be transmitted in two forms:

- Ongoing background information that educates the public about fire hazards. In this context, the information provided by the meteorological service is primarily climatic;
- More detailed information during high-risk periods. Such information should be conveyed by the most appropriate media to warn concerned population groups of the abnormally high levels of risk. In the meteorological context, such information concerns the short- and medium-term.

Meteorological services are most involved with the second element above.

7. CONCLUSION

In conclusion, meteorological services should cooperate fully and openly with the services responsible for preventing and fighting forest fires. Even where the meteorological network is not very well-developed, easily applicable methods exist for forecasting periods of highest fire risk. Utilizing these methods, a system of preventive measures can be established to improve the means of coping with fires. In addition, information provided by the media during periods of high fire risk will reduce the number of outbreaks. A small number of accurate forecasts of high fire-risk levels are virtually all that is required to gain the level of trust discussed in this paper. These forecasts should be provided a few days in advance and, with recent improvements in the quality of medium-term forecasts, such a service is now within our capabilities.

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