EVALUATION OF FOREST FIRE DANGER IN SPAIN BY MEANS OF NOAA AVHRR IMAGES

P. Illera, A. Fernández, A. Calle and J. L. Casanova
University of Valladolid. Dpto. Física Aplicada I

E. T. S. de Ingenierías Agrarias de Palencia
Avda. de Madrid 57-34071 PALENCIA-SPAIN
Tel: 34 79 729048 Fax: 34 79 712099

ABSTRACT

This work presents an analysis of the possibility of large-scale forest fire danger evaluation by means of NOAA-AVHRR images. The danger indicators are based on monitoring the hydric stress of the vegetation and the results obtained following two different approaches are presented. The first procedure is based on the analysis of the NDVI temporal evolution, a decrease in which is supposed to be related to an increase in fire danger. The second indicator is derived from the slope between surface temperature and NDVI. They present a linear relationship whose slope is a measure of evapotranspiration in forests and can be used as an indicator of water stress. To desing and test the danger indices, AVHRR images captured and processed daily by the University of Valladolid have been used. Forest fire data provided by the Spanish Forestry Service have also been available. The study has been carried out in the East of Spain from April to September of 1994 that was a period with a very high amount of large-scale (>1,000 ha) forest fires. The superimposition of images and ground data allow for the setting up of indicators that can be useful in monitoring the danger of large-scale forest fire ocurrence.

1. INTRODUCTION

Forest fires are one of the main problems facing Spanish mediterranean forests. Data from the summer of 1994 provide results which can only be described as catastrophic. In the Autonomous Comunities of Catalonia and Valencia, fires destroyed a total surface of 193,710 hectares. In addition, five fires affected areas of over 15,000 ha. Although the situation could be qualified as extreme, the problem arises each summer, therefore developement of risk indices for large fires is very beneficial.

The AVHRR radiometer on board the NOAA satellite series offers good potential for monitoring the state of living vegetation. It provides multispectral images over large areas with a satisfactory temporal resolution as it sweeps over the same area of land several times a day. The first two AVHRR channels allow for the calculation of NDVI type vegetation indices that offer a good correlation with different physiological variables. The radiometer is also equiped with three thermal channels, useful for calculating surface temperature.

NOAA images have been used for three fire monitoring applications (Chuvieco and Martín, 1994): monitoring vegetation water stress before the fire, fire detection and mapping the extent of the burnt area.

We have developed an operational system for fire monitoring using NOAA AVHRR images which we obtain by means of a HRPT receiver installed in our Department (Illera et al., 1995; Fernández et al., 1995). The system allows for automatic fire detection, using local thesholds in the difference between channels 3 and 4 temperatures. The mapping of burnt areas is also automatically obtained by applying change detection techniques of difference and regression to the NDVI values before and after the fire.

The system may also be used to calculate danger indicators by monitoring the water stress of the vegetation. In this work the results obtained following two different approaches are presented. The first procedure is based on the analysis of the NDVI temporal evolution. A decrease in the NDVI value may be linked to an increase in water stress, with the resulting increase in fire danger (Paltridge and Barber, 1988; López et al., 1991; Burgan and Hartford, 1993). As a danger indicator, the sum of the slopes of the curve of the NDVI temporal evolution from spring to the period at which the fire occurred has been studied.

The second indicator is derived from the slope between ground temperature and NDVI values. Several authors (Nemani and Running, 1989; Goward and Hope, 1989) have suggested that this slope is related to the ratio between sensible and latent heat flux and can be used as a measure of water stress in forests.

In order to test the reliability of the danger estimates, these two indicators are generated and compared to ground data measured by the Spanish National Forestry Service (I.C.O.N.A.). A previous study carried out using data of 1993 (Illera et al., 1996-b) led to the conclusion that the NDVI temporal evolution can be useful in monitoring large-scale forest fire danger. Due to this, in this work only fires of sizes over 1,000 ha have been analysed.

2. AREA OF STUDY

Figure 1 - Area of study

The study has been carried out in the area shown in Figure 1. It deals with the 20 provinces which comprise the various Autonomous Communities of Aragon, Castile la Mancha, Catalonia, Valencia, Murcia and Andalusia. These regions constitute the Eastern part of the Iberian Peninsula.

These woodland areas are predominantly comprised of conifer trees, with pines being the dominant species. One should also point out the presence of the leafy holm oak. Finally, we should also bear in mind the importance of shrubs, bushes and different types of undergrowth.

As regards the incidence of forest fires, we are dealing here with the area most prone to this phenomena in Spain. According to the data supplied by the Spanish Forestry Service I.C.O.N.A., one should emphasise also the importance of large-scale fires, which led to the disappearance of 263,000 ha only in the Summer of 1994. Among the causes we should emphasise the role played by the prolonged drought which affected these regions as well as the high temperatures reached in the summer months. July, August and September are the highest risk months.

3. DATA

In this study the NOAA-AVHRR images obtained daily by the University of Valladolid have been used. We have a NOAA-HRPT receiver which enables us to obtain images of up to 2,000 x 2,000 km with a radiometric resolution of 10 bits. The images are calibrated (Kaufmann and Holben, 1993) and are geo-referenced to a UTM projection, with a spacial resolution of 1 x 1 km by means of our own software (Illera et al, 1996-a).

Images for the year 1994 have been used. The period corresponds to the months from March to September, given that the period of greatest fire risk is the Summer. In order to analyze the NDVI temporal evolution, the Maximum Value Composites (MVC) are generated corresponding to periods of 10 days. The surface temperature is obtained from May to mid-July combining the data of the channels 4 and 5 by means of a split-window algorithm.

Ground data measured by the Spanish Forestry Service I.C.O.N.A. have also been used. The dates of the fires, the affected areas and location in a 10 x 10 km network have been employed. This location gives rise to a certain inaccuracy when the images and ground data are superimposed. We focussed exclusively on the large-scale fires (> 1,000 ha) which broke out between April and September in the entire area under study. Our sample consists of 25 fires, representing 264,522 ha. To avoid location inaccuracies, the fires have also been mapped using the NDVI values before and after their outbreak, an aplication which constitutes one of the options of our fire monitoring algorithm (Fernández et al., 1995).

4. NDVI EVOLUTION AND FIRE DANGER

The NDVI is related to diverse physiological variables and in particular to photosynthetic activity and could be an indicator of the water content of the vegetation. The temporal evolution of the NDVI enables us to carry out a monitoring of the moisture of the vegetal fuel. In Figure 2 the evolution curves are shown in sectors of the study area which correspond to different vegetation covers. In forestry areas a decrease in the index can be related to an increase in the hydric stress and, therefore, to an increased fire danger.

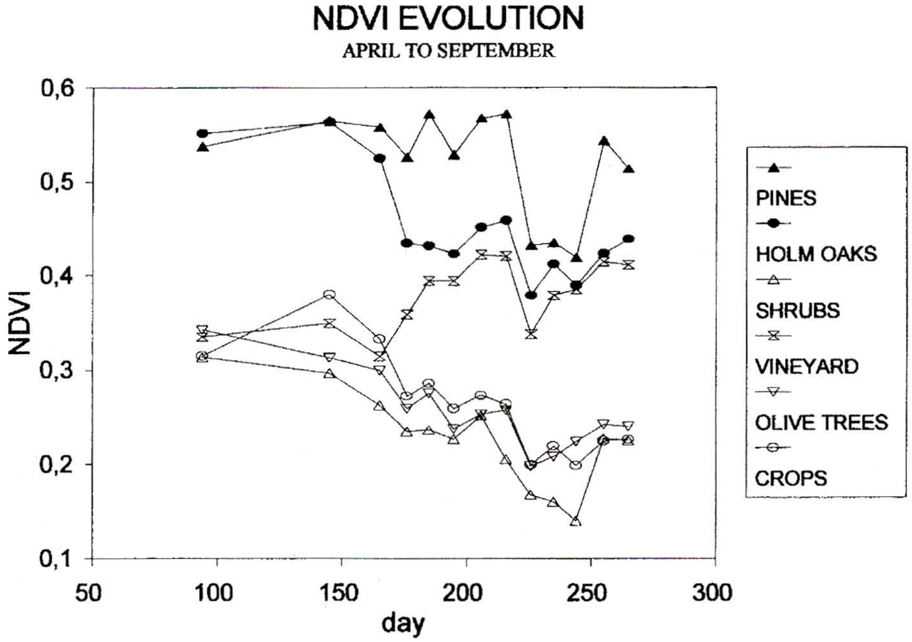

Figure 2 - NDVI temporal evolution from April to September in sectors of the study area which correspond to different vegetation covers

Due to the fact that we do not have long time series, as a danger indicator we have studied the sum of the NDVI slopes from March to the period in which the fire breaks out:

$$AS_n = \sum_{i=1}^{n} \frac{NDVI(t_i) - NDVI(t_{i-1})}{t_i - t_{i-1}}$$

Where t is the day of the year. We call this indicator accumulated slope or AS. It is a cumulative indicator and we would expect it to present negative values during the periods of danger. We also presume that its decrease would suppose an increased water stress or an increased fire danger. To text this index, a sample of 22 fires corresponding to the summer months has been used. They affected to a surface of 256,758 ha.

Given that we have a NDVI-MVC image every 10 days, we can calculate the AS value with that frequency. In Plate 1, we present the outcome for the period from 2 to 11 of July, 1994. A certain confusion can be observed between those areas with different land uses and similar AS values. If we observe Figure 2, we arrive at the conclusion that the negative values may correspond to crops, shrubs and bushes and forestry areas with a fire danger. The vineyards (in the process of growing at this time) and also the irrigated crops present positive values. In conclussion it is necessary to include a map of land uses or at least a map of forestry areas in the analysis.

The curves shown in Figure 2 suggest that the confusion among the different types of vegetation can also be avoided by using the cumulative NDVI (or the NDVI integral) calculated during the same period. The forestry areas give high values as can be observed in Plate 2, which corresponds to the same period as the AS image and in which the main wooded areas of the region have values above the average and are brought out in green. Bearing this in mind, we propose to use the NDVI integral as a mask and to analyze the risk factors only in the areas with above the local (province) average values. If the ground data and the integral values are superimposed, we conclude that 88% of the large-scale fires and 98% of the burnt surface register above the average integral values. A similar result was achieved in the case of any-size fires, using a sample of 617 fires in 1993. 58% of the cases and 87% of the burnt surface had above average integral values (Illera et al., 1996-b).

As an initial conclusion, the NDVI temporal evolution or the AS values present a lot of confussion between different vegetation types. If there is not a map of vegetation avalaible, it would appear to be advisable to use the NDVI integral as a mask in order to eliminate non-forestry uses from the area of studio. The result may be of great interest in areas where an up-to-date mapping of land uses does not exist.

In order to analyze the behaviour of the proposed danger indicator, the values are generated and compared with the official fire data. The superimposition of the accumulated slope and the ground data allows us to reach the following conclusions:

The forest fires occur at low AS values, but these change according to the area and date. The results can be seen in Figures 3-A and 3-B. In the first case, the affected areas are presented in relation to their AS value. In general terms, fires produces at negative values of the AS but we do not find a clear tendency. In the second figure, the tipified index value is shown using the average and standard deviation corresponding to the AS values calculated for all the pixels in the province and in the corresponding 10-day period. A value of -1 represents an area where the AS value is one standard deviation below the average of the province. A high negative value represents an area with an AS much lower to the local average in this particular period. The figure suggests that the tipified AS can be a good indicator of the areas most prone to suffer a large scale forest fire in a given date and location.

This confirms the results obtained in the previous study carried out with data of 1993. A sample of 617 fires with sizes ranging from 0 to 6,000 ha was used. Small fires took place for all types of values of the AS index, but there seemed to be a relationship between the affected area and the AS in the case of large-scale fires (Illera et al., 1996-b). The result can be explained if we think of only one of the many risk factors involved in forest fires is being taken into account; namely that which is associated to the hydric state of the vegetation. If the vegetation is in a state of danger, it seems logical to assume that the chance of a fire spreading and being difficult to control is likely to increase.

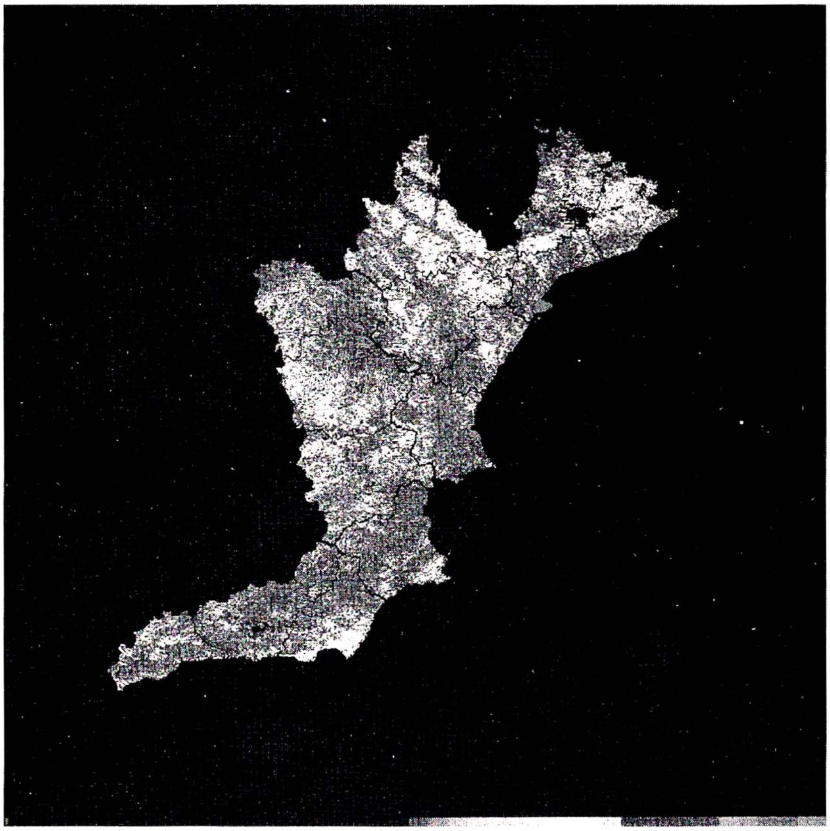

Figure 1 - AS image for the period from 2 to 11 July, 1994

See plate V at end of volume

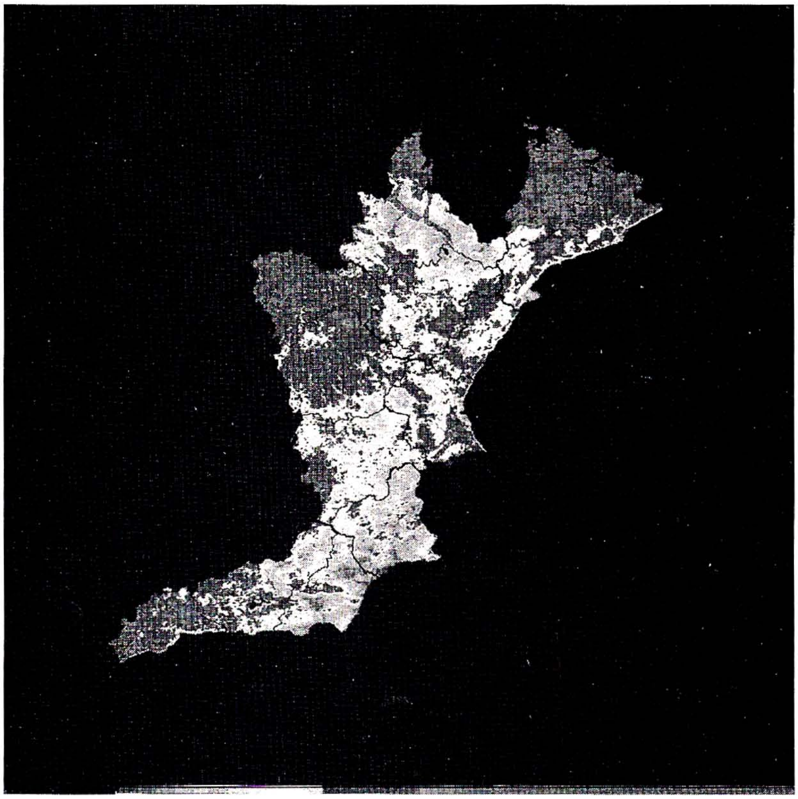

Figure 2 - NDVI integral for the period from 2 to 11 July, 1994

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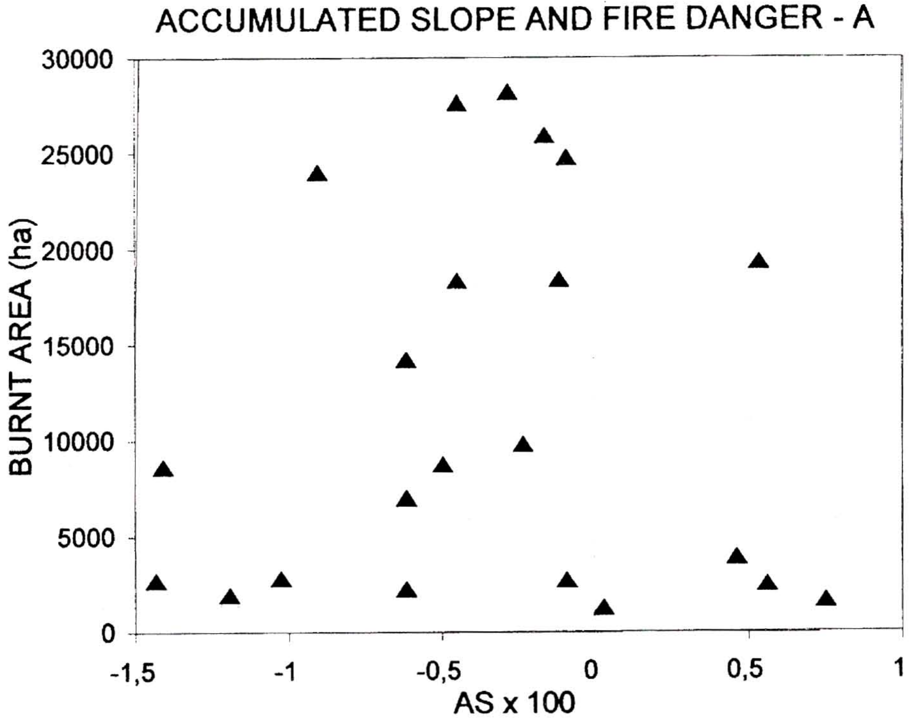

Figure 3a

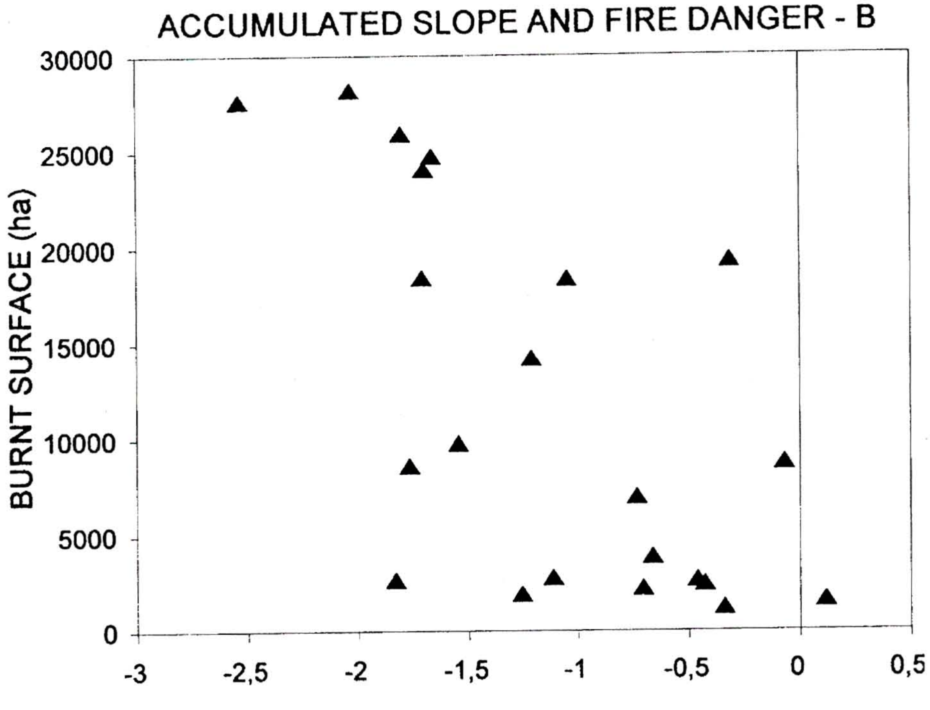

Figure 3b

Figures 3a and 3b - Values of the AS for the large-scale fires in the Summer of 1994. There seems to be a relationship between the AS value and the burnt surface, but it depends on the area and epoch. This can be seen in Figure 3b, where the AS has been typified using the average value and standard deviation of the province (area surrounding the fire) and the date of danger (10 day MVC period before the fire occurrence)

Finally, in Table I, the results obtained for the Summer, 1994 sample are shown: a danger situation is supposed to exist for AS tipified values less or equal than -1. The index is useful in 59% of fires responsible for 81% of the burnt area. In Figure 4, the danger image is presented for the same period as in the plates above.

Table 1 - NDVI evolution and fire danger. A danger situation is suposed if the AS tipified value is less or equal than -1

	DANGER	NO DANGER
NUMBER OF FIRES	13 (59%)	9 (41%)
BURNT SURFACE (ha)	207,471 (81%)	49,287 (19%)

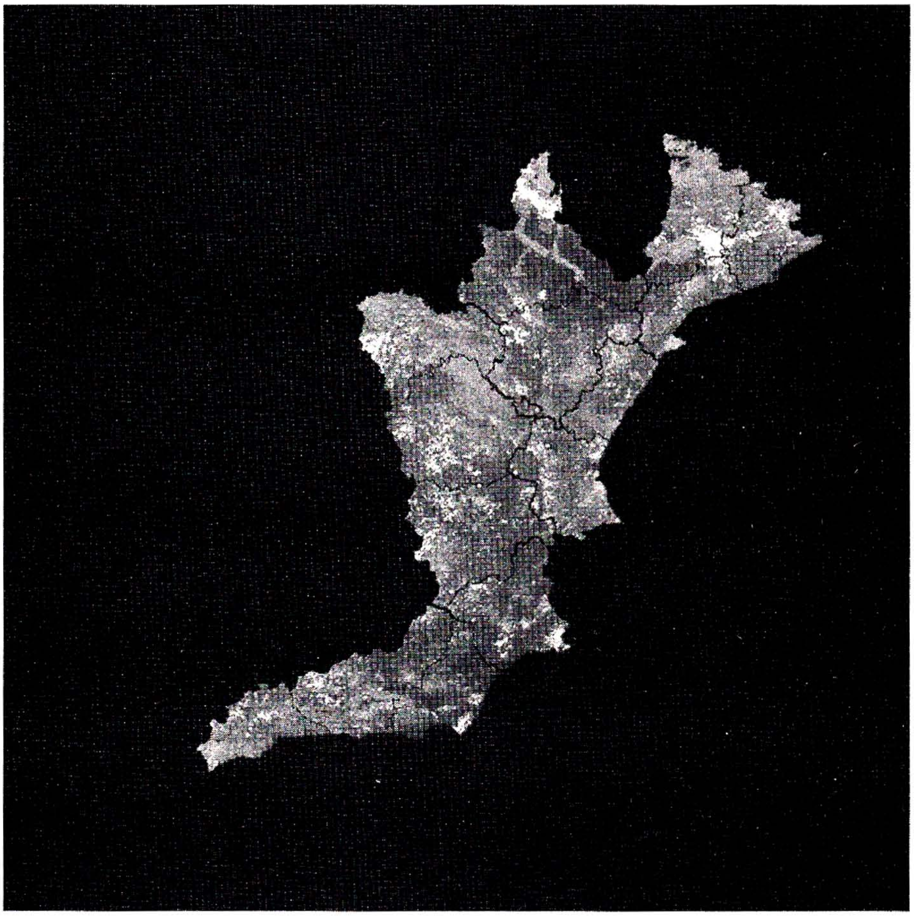

Figure 4 - Danger image for the period from 2^{nd} to 11^{th} of July. Areas in danger are marked in white

See plate VI at end of volume

5. NDVI-SURFACE TEMPERATURE RELATIONSHIP AND FIRE DANGER

The second danger indicator is derived from the relationship between the surface temperature and the NDVI. The surface temperature is one of the basic elements affecting the energy balance on the earth´s surface, as it determines the thermal radiation emitted and the fluxes of sensible and latent heat. The above mentioned fluxes and, therefore, the radiative balance (and the temperature value itself) vary according to the presence or absence of vegetation and also with the density of vegetation cover. Several authors (Nemani and Running, 1989; Goward and Hope,

1989) have suggested using the relationship between the surface temperature and the amount of vegetation, measured by means of the indices of the NDVI type, as an indicator of the ratio between actual and potential evapotranspiration or as an indicator of water stress.

On the other hand, some studies (Vidal et al., 1994) show the existence of a relationship between the number of forest fires and the ratio between actual and potential evapotranspiration. This suggests that we can use the above mentioned indicator as a way of estimating forest fire danger, due to the water stress of the vegetation.

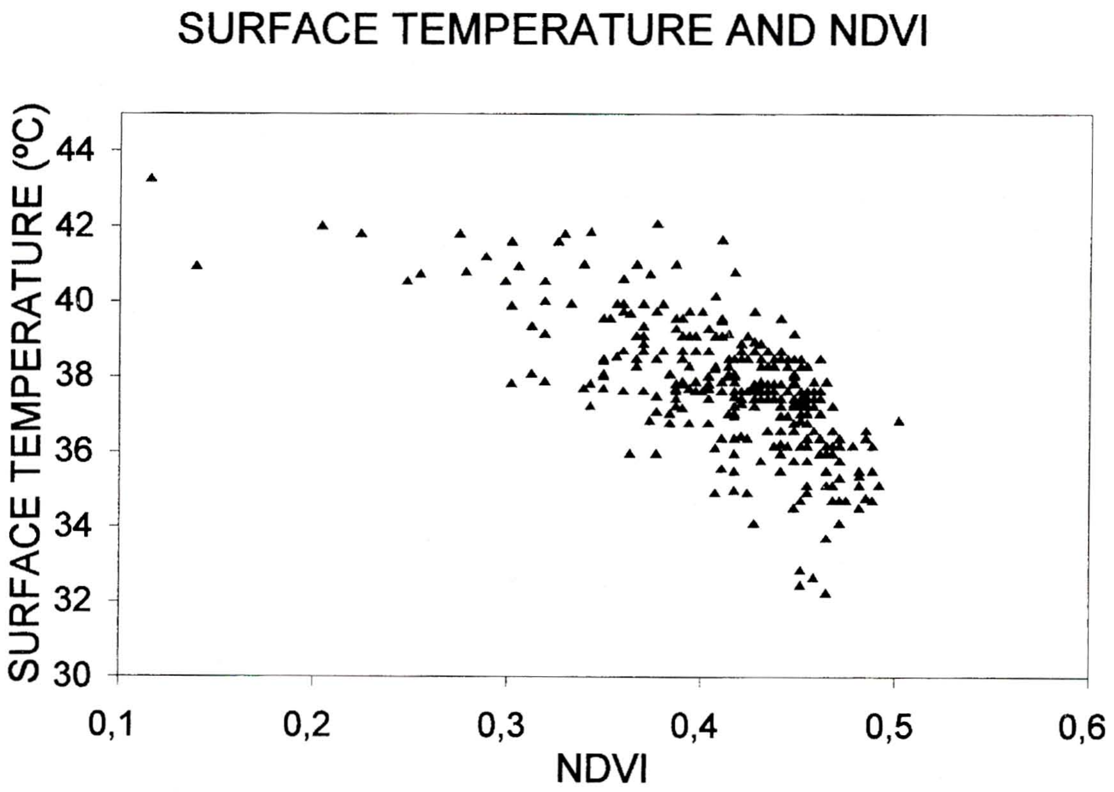

Figure 5 - Relationship between the surface temperature and the NDVI in a 20 x 20 km sector of the study area

In Figure 5, we show the relationship between surface temperature T_s and NDVI in one 20 x 20 km sector of the study area. A linear negative-slope relationship can be observed, which means that the temperature decreases when the density of the vegetation cover increases. This is due in part to evapotranspiration or, in other words, to the increase in the latent heat flux. The slope of the diagrams is thought to be related to the water stress. A greater slope (in absolute value) implies a higher temperature or an increase in stress.

On the basis of these observations, we have analyzed the relationship between the above mentioned slope and the danger of large-scale forest fires occurring. In order to calculate the slope of the T_s-NDVI relationship we worked in areas of 20 x 20 km, using the procedure outlined by Nemani (Nemani et al., 1993). The slope is calculated using daily images and we present the results for the period from 1 May to 15 July. These results refer to 19 forest fires which destroyed 200,476 ha.

In Figure 6, the temporal evolution of the slope is shown from May to mid-July in a region of Valencia where a forest fire affecting 5,348 ha occurred on 22 June. The evolution curve can be seen in the areas surrounding the fire, taking only the pixels relating to forestry use, determined by means of a forestry mask derived from CORINE land cover data base. This refers to an area of 100 x 100 km centred on the fire, which supposes 25 cells of 20 x 20 km. The normal values are maintained at between -10 and -30. The positive values correspond to situations in which there are a lack of fitting or insufficient data to apply the procedure in the 20 x 20 km zone, due to the presence of clouds. In the same figure the evolution

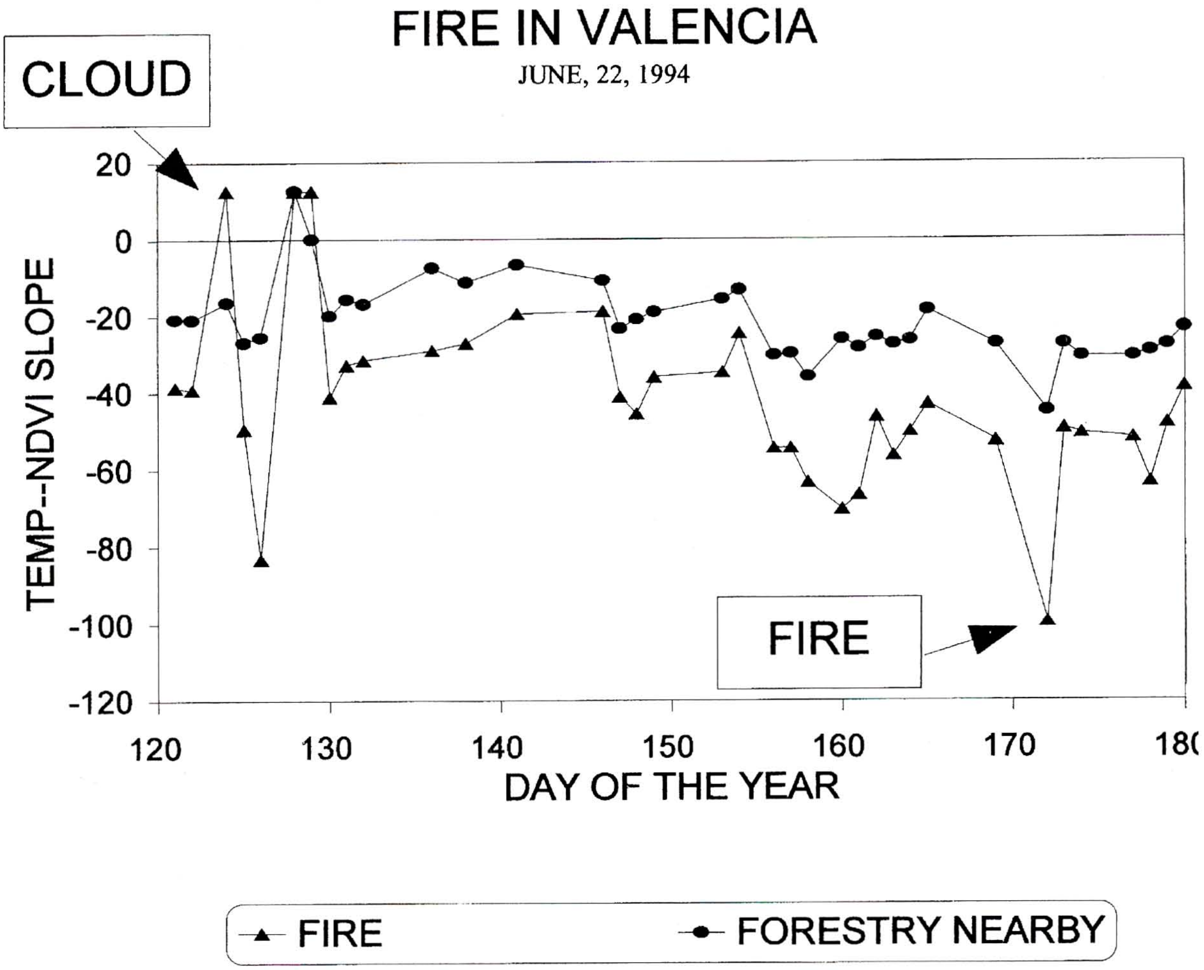

Figure 6 - Slope of the relationship shown in Figure 5 and the fire danger. The slope is presented in the fire area and also in the forestry pixels of the 100 x 100 km area surrounding the fire. The decrease in the slope value can be related to an increased water stress. It can be observed before some fire occurrence.

can be seen in the area affected by the forest fire. Peaks can be observed in some periods with higher negative values of the slope. A decrease of the slope appears on the day or period before the fire outbreak. If the analysis of the evolution curves for all the fires in the sample is carried out, a decrease of the slope is found in 13 fires (68% of the total sample) that affected 134,907 ha (67%) as can be seen in Table II. We conclude the slope could be a good indicator of fire danger although a further research is necesary to establish the danger thresholds.

Table II - NDVI-surface temperature relationship and fire danger.

	DECREASE IN THE SLOPE	NO DECREASE IN THE SLOPE	CLOUDS OR NO DATA
NUMBER OF FIRES	13 (68%)	3 (16%)	3 (16%)
BURNT SURFACE (ha)	134,907 (67%)	29,425 (15%)	36,144 (18%)

6. CONCLUSIONS

In this paper the usefulness of the NOAA-AVHRR images in order to estimate the danger of the outbreak of large-scale forest fires has been analysed. The study area corresponds to the East of the Iberian Peninsula and the period to that of the Spring and Summer of the year 1994. Daily images, obtained by the receiver installed in our Department, have been used. In order to determine the validity of the danger indicators ground data taken by the Spanish Forestry Service, I.C.O.N.A., have also been employed.
Two procedures for estimating the danger of forest fires are analyzed. Firstly, the NDVI temporal evolution is used. In order to do this, NDVI-MVC images are generated every ten days and the sum of the slopes of the NDVI evolution curve or AS (Eq. 1) are calculated from Spring to the period before of the forest fire occurrency. A previous study with data from 1993 in the Valencia region suggested that the index is useful for estimating the danger of large-scale forest fires. The analysis of the AS values and their superimposition with the large-scale forest fires ground data in 1994, allows us to reach the following conclusions:

The variations in the NDVI (or the AS) present similar values for the different vegetation types which leads to a lot of confussion between different vegetation classes.To avoid confusion between areas with different land use, it is necessary to employ a forestry map. If there is no one available, we suggest using the NDVI integral in the same period of the year. 88% of forest fires and 98% of the affected area correspond to intergral values higher than those of the average of the province during that period. This can be of interest in areas where there is a lack of mapping of the vegetation.

The AS can be useful in detecting the areas most prone to suffer large-scale forest fires in a particular date. To do it operationally, the AS is tipified with respect to the average and standard deviation of the province in the corresponding ten-day period. 59% of the cases and 81% of the burnt area have a value of the AS less or equal than the average minus one standar deviation and are determined to be in danger according to this procedure. Moreover there seems to be a relationship between the AS tipified values and the fire size (Figure 3-b) and the index could be useful to give the chance of a fire spreading and being difficult to control.

The second procedure used consists of analyzing the slope of the relationship between the surface temperature and the NDVI. A decrease in the slope value would mean an increase in water stress, for which we use the above mentioned slope as a danger indicator. In this case the slope is calculated in areas of 20 x 20 km by using the daily images of the NDVI and the surface temperatures obtained by means of a split-window procedure. We analyze the usefullness of the indicator in the case of large-scale fires in the period from May to mid-July, 1994.

An initial analysis of the slope evolution and the superimposition with the forest fire data allows us to detect as in danger 68% of the cases which correspond to a 67% of the burnt area. The results also indicate that the indicator must be calculated on a daily basis. Finally, a further study would be advidsable to better establihs the behaviour of the indicator and to determine the adecuate danger thresholds.

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