Automatic algorithm for the detection and analysis of fires by means of NOAA AVHRR images

P. Illera, A. Fernández and J.L. Casanova

Universidad de Valladolid. Dpto. de Física Aplicada I
47071 – Valladolid. Spain.
Tel. and Fax: 34 83423130

ABSTRACT

Forest fires are a major environmental problem in Mediterranean regions, with large areas being affected each Summer. Remote Sensing is a powerful tool in the study of this phenomenon. It has been used in recent decades for detecting fires, predicting risk and evaluating losses. The AVHRR radiometer is one of the best observational systems for fire monitoring. It provides multispectral sampling and offers good repetitivity, sending data from a single area up to four times a day. In this study, an automatic algorithm for the detection and analysis of fires has been developed. It permits the treatment of large fires as well as those smaller than one pixel. Infrared AVHRR images are used together with the multispectral technique proposed by Dozier. Fires can thus be detected and a calculation made of their temperatures and affected areas. The results of the algorithm's application to different situations in Spain are presented. These results have been obtained using AVHRR images received and processed directly in our department.

1. INTRODUCTION

Forest fires represent one of the most serious environmental problems which exist in Mediterranean regions, with large areas of forest being destroyed by fire each Summer. This phenomenon has increased in Spain over the last decade and in spite of a greater awareness as regards the seriousness of the problem, fires have caused huge economic losses as well as greater but more difficult to calculate ecological damages.

Remote sensing allows us to obtain information about large wooded areas, as a result of which it has been used over the last two decades in the study of forest fires following different approaches: fire detection, determining affected areas, analysis of the evolution of the plant canopy after the fire and prediction of risk.

The AVHRR radiometer, on board the NOAA satellites, offers one of the best observational systems for fire monitoring. The AVHRR provides multispectral data covering wide areas and offers excellent temporal sampling, as it passes over the same part of the earth four times a day. NOAA AVHRR images have basically been used for detecting fires and analysing both those areas which are affected and those which may be at risk.

At high temperatures, fire points emit high radiances in the atmospheric window of [3-5μm]. Channel 3 of the AVHRR is, therefore, suitable for detecting fires (Matson *et al.*, 1984; Muirhead and Cracknell, 1985; Kaufman *et al.*, 1990; Lee and Tag, 1990). In addition, the multispectral technique proposed by Dozier (Dozier, 1981; Matson and Dozier, 1981) provides us with a calculation of the fire temperature as well as the affected areas, combining data from channels 3, 4 and 5 (Matson *et al.*, 1984; Flannigan and Vonder Haar, 1986; Robinson, 1991). As regards the prediction of areas at risk, the accumulation of plant fuels may be observed by studying the evolution of NVDI type vegetation indices, derived from AVHRR channels 1 and 2 (Miller *et al.*, 1983; Paltridge and Barber, 1988; López *et al.*, 1991). These data, together with other risk factors, integrated into a geographic information system, allows us to develop the corresponding models.

Our aim is to design an operational system to tackle the previously mentioned points, using NOAA AVHRR images which we receive directly from the passing satellites by means of an HRPT receiver installed in our department. In this study, an automatic algorithm for the detection of fires as well as the calculation of temperatures and affected areas is presented. The algorithm is developed differently for detecting fires smaller than one pixel (hotspots), and large scale fires where several pixels are affected. The results of its application to various situations in Spain are also presented.

2. DATA SET

The study presented here has been carried out using NOAA AVHRR images captured in the University of Valladolid. We have an HRPT-NOAA receiver, which we acquired from the University of Bradford, and which allows us to capture images of up to 2000 x 2000 km^2, with a resolution of 10 bits. The signal received contains the radiance values of the HIRS, MSU, SSV and AVHRR radiometers. In order to tackle the detection and analysis of fires, we have used AVHRR channels 3, 4 and 5 which correspond to the following spectral bands:

Channel 3, infrared: 3.55 to 3.93 et μm
Channel 4, infrared: 10.3 to 11.3 μm
Channel 5, infrared: 11.5 to 12.5 μm

The images are calibrated in order to obtain brightness temperatures, taking into account the non-linearity of the sensor and they are georeferenced to within an error of less than one pixel, all by means of software designed by us.

3. FIRE DETECTION AND ANALYSIS

The difference in wavelengths in which channels 3 and 4 of the AVHRR operate, allows for the detection of fires as well as the calculation of their sizes and temperatures. In order to do this, we have used the multispectral method proposed by Dozier (1981), with AVHRR channels 3 and 4. The method assumes that the radiance from a pixel integrates the input from two different temperature sources: a fire at temperature T_F and vêgetation at temperature T_V which occupy the said pixel in proportions p and 1-p respectively with $0 \leq p \leq 1$.

The way in which the spectral responses from two different temperature sources are averaged in a pixel depends on the wavelength in which the sensor operates. If one part of the pixel is hotter, it will contribute proportionally with more radiance for short infrared wavelengths. For a pixel which contains a fire, a high brightness temperature in channel 3 may therefore be expected. The brightness temperature in channel 3 will, likewise, be greater than that corresponding to channel 4. This will allow us to detect fires automatically using AVHRR images.

Assuming a pixel with two areas differentiated at temperatures T_F and T_V which occupy portions of the total surface given by p and 1-p respectively, the radiances detected in AVHRR channels 3 and 4, without taking into account atmospheric emission or attenuation and supposing that the earth's surface behaves like a blackbody, may be expressed as:

$$L_3\,(T_3) = p.L_3\,(T_F) + (1\text{-}p)\,.L_3\,(T_V)$$
$$L_4\,(T_4) = p.L_4\,(T_F) = (1\text{-}p)\,.L_4\,(T_V) \qquad (1)$$

where T_3 and T_4 are the brightness temperatures in the respective channels and:

$$L_i\,(T) = \frac{\int_{\lambda_1}^{\lambda_2} B(\lambda, T)\,.\phi_i\,(\lambda)\,.\,d\lambda}{\int_{\lambda_1}^{\lambda_2} \phi_i\,(\lambda)\,.\,d\lambda} \qquad (2)$$

B(λ,T) being the radiance of the blackbody and $\Phi_i(\lambda)$ the response of the sensor for the i channel, which operates in the [λ1,λ2] band (Kidwell, 1986).

Given that T_3 and T_4 are obtained from the AVHRR images, if the temperature of the vegetation T_V is measured from the pixels adjacent to the one which is burning, solving equations (1) allows us to obtain fire temperature T_F and the extent of the area in flames.

The method described is only applicable when the pixel is only partially burning and contains areas at temperatures T_F and T_V. An analysis of hotspots is therefore provided. With large scale fires, it will be used to detect the perimeters, while in pixels totally surrounded by others which are burning, it is assumed that p=1, in other words the whole of the area is affected.

4. AUTOMATIC ALGORITHM

As we have already pointed out, in order to develop the automatic algorithm, two types of situation have been distinguished: large scale fires, where more than one pixel is affected, and fires smaller than one pixel, which are more difficult to detect.

4.1 Large scale fires

4.1.1 Detection

In this case, detection is based on the high channel 3 radiance of pixels at high temperatures. Likewise, these pixels offer a more reduced response in channel 4. The effect is illustrated in **images 1 and 2**, in which the brightness temperatures of both channels corresponding to a fire which occured in NE Spain, near the Ebro delta, on July 21, 1993 are presented. The images correspond to 4^h 19^m. As may be deduced from the associated colour scale, the affected pixels show a T_3 temperature which is much higher than in the surrounding ones, while the effect is less noticeable in channel 4. In **figure 1**, both brightness temperature values are shown along a line which crosses the fire. The phenomenon described can readily be observed and is repeated for all the fires analysed.

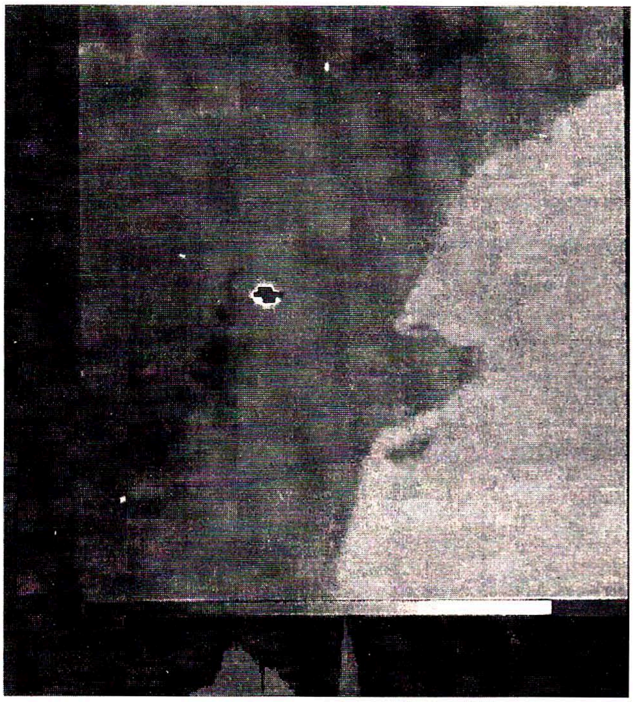

Image 1 - NOAA 11 image on July 21, 1993 at 4h 29m. It corresponds to channel 3 brightness temperatures. A fire in Alfara (Tarragona) may be observed.

In order to decide whether a pixel corresponds to a fire we thus use the difference $T_3 - T_4$ as a threshold, which should be greater than 8 K. In **image 3**, the difference $T_3 - T_4$ is used to detect the forest fire in the previously mentioned case. Channel 4 values are used for the rest of the pixels. The reliable detection of fire pixels offered by the threshold can be seen. Saturated pixels are considered to form part of the fire, irrespective of the value of the difference.

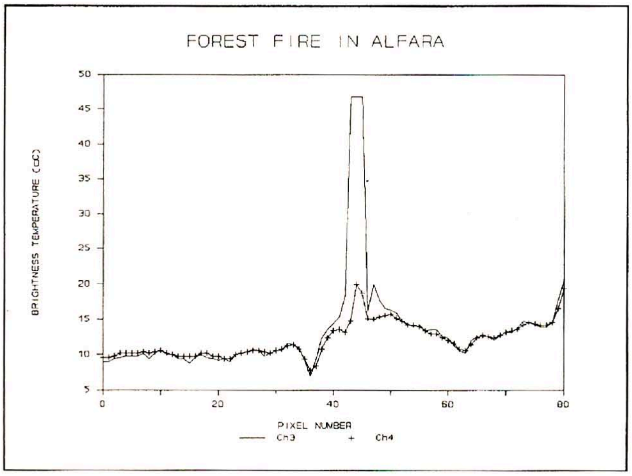

Figure 1. – Channel 3 and 4 temperature along a line crossing the fire

Image 2 - Same as for the previous but for channel 4. The fire is not detected as well as in channel 3.

Image 3 - Fire detection by using $T_3 - T_4$ differences as a treshold, superimposed on image 2.

The algorithm automatically detects the affected pixels and indicates whether they correspond to the same fire. It also gives the UTM coordinates of the pixels of possible fires which appear in the image. Finally, the possibility of carrying out a follow-up of the fire's temporal evolution is considered, so that the final result is obtained by means of detection carried out over several images.

This $T_3 - T_4$ thresholding procedure has already been used by other authors (Flannigan and Vonder Haar, 1986; Kaufman *et al.*, 1990; Lee and Tag, 1990). The difference in the thresholds proposed values sugests the advisability of a deeper study. The algorithm results will be compared to ground data and the possibility of deriving the thresholds from the difference values in the area surrounding the pixel will be taken into account.

4.1.2 Analysis

Once the pixels affected by the fire have been determined, the total surface is calculated by applying the Dozier multispectral technique to the perimeter and supposing p=1 in the pixels totally surrounded by others which are burning. The p values, together with pixel size, calculated by means of the georeference, allow the total surface to be worked out.

In order to solve equations (1), the T_3 and T_4 values are obtained from an analysis of the pixel's image data. T_V is obtained as an average of the temperatures of the pixels which surround the one studied, calculated using the split-window method, by means of the following equation proposed by Price (1984):

$$T_V = T_4 + 3.3 \cdot (T_4 - T_5) \qquad (3)$$

In order to determine the solution (p, T_F), we have developed a very simple method which is described in **figure 2**.

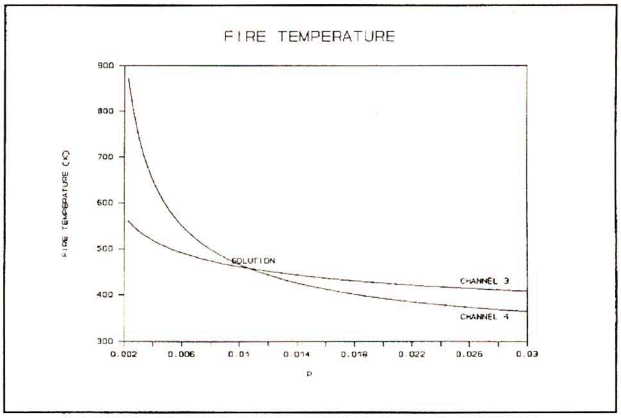

Figure 2 - Solving of equations (1)

It involves calculating the T_F values corresponding to the different p values, with the two equations (1) separately. The system's solution corresponds to the p value which leads to the same result for T_F in both equations.

As a result of the analysis, the algorithm provides the total surface which is affected as well as the perimeter temperatures for unsaturated pixels. If saturation is present, we assume p=1, even for pixels in the perimeter.

In **table 1**, the results are offered for the method's application in the case of the fire in the images.

Table 1 - Algorithm results for the fire in images 1 and 2. Total size 1253 ha

ROW	COL	X_{UTM} (31)	Y_{UTM} (31)	T_F (K)
360	1068	283947	4531420	767
360	1069	284740	4531221	$T_4 < T_V$
361	1067	282834	4530563	SAT.
361	1069	284422	4530163	SAT.
362	1065	280930	4529906	$T_4 < T_V$
362	1066	281723	4529706	SAT.
362	1070	284900	4528903	SAT.
362	1071	285694	4528704	568
362	1072	286491	4528504	SAT.
363	1066	281409	4528648	689
363	1067	282203	4528448	$T_4 < T_V$
363	1068	282997	4528246	511
363	1070	284584	4527846	488
363	1071	285378	4527645	534
364	1069	283473	4526989	568

4.2 Hotspots

4.2.1 Detection

The detection of fires of less than one pixel is also based on the difference in brightness temperature $T_3 - T_4$, but in this case the responses in channel 3 are smaller and the threshold needs to be carefully chosen.

In order to do this, we used the procedure proposed by Lee and Tag (1990). It is based on the Dozier technique and involves fixing the threshold T_F above which hotspots are detected. Given a possible hotspot, T_V is determinated and equations (1) allow us to calculate the pairs of values

(T_3, T_4) which correspond to variations of p between 0 and 1. An example is given in **figure 3**. For each T_4 value, the curve described gives the threshold temperature T_3 above which it is decided that there is a hotspot in the pixel. The algorithm detects the hotspots in the image and gives their UTM coordinates.

As an example, we have presented a situation corresponding to July 9, 1993 at $8^h 35^m$. The application of the algorithm with $T_F = 573$ K results in the detection of 4 hotspots in the South of the Iberian Peninsula. In **image 4**, the image of channel 4 is shown, on which the hotspots found with the algorithm have been marked. These points are not easily detectable in the channel 3 image. Raising T_F obviously results in a reduction of the number of hotspots found using the method.

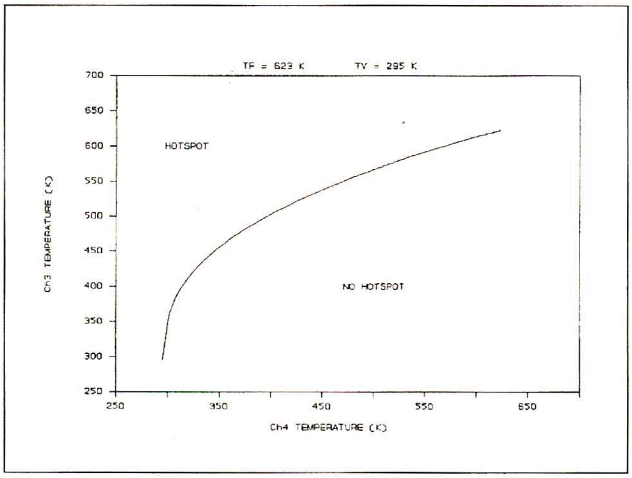

Figure 3 - Choice of thresholds for the detection of hotspots

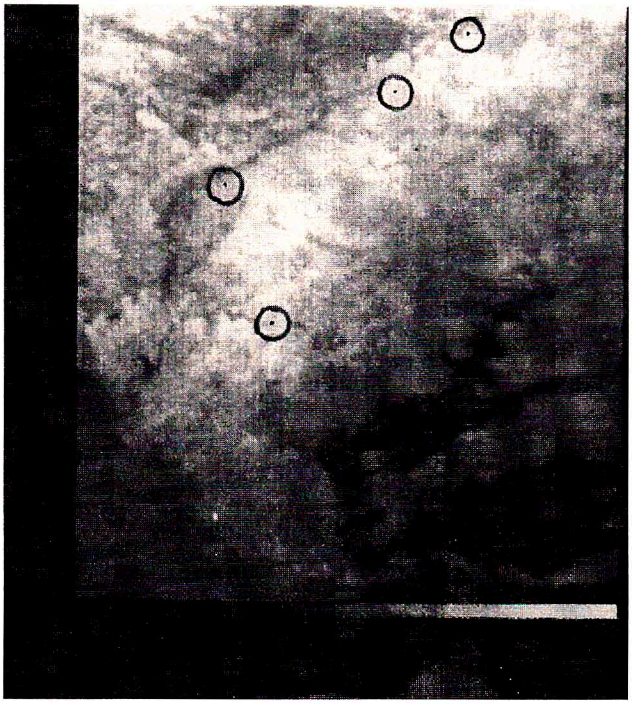

Image 4 - Hotspots detected on July 12, 1993 at 8h 35m superimposed on the channel 4 temperature brightness image. They are not visible in the channel 3 image. The images correspond to NOAA 9.

4.2.2 Analysis

Once a hotspot has been detected, the Dozier technique allows us to calculate the affected area as well as the fire temperature. In **table 2**, the results for the previously mentioned case are presented.

Table 2 - Algorithm results for hotspots on July 9, 1993 at 8^h 35^{mn}

ROW	COL	X_{UTM} (30)	Y_{UTM} (30)	T_F (K)	AREA (m^2)
698	761	365812	4200139	674	616
720	727	332756	4182557	416	676
755	648	260304	4159026	1335	595
806	671	263226	4100538	410	644

From the results which we have obtained of the algorithm's application to different situations, fire detection appears to be adequate. As regards analysis, we generally found low p values in the perimeter pixels. Likewise, the solutions vary greatly when temperature T_4 is similar to T_V and the method can not be used when the value is less, which could lead to problems if the variability of the temperatures in the pixels which surround the fire is considered.

In order to improve the analysis technique, it would seem advisable to improve temperature calculation by means of atmospheric correction. Similarly, it is necessary to study the influence of the existence of smoke, which may modify the temperature values used as data in the model.

5. CONCLUSIONS

In this work we have presented an automatic algorithm for the detection and analysis of forest fires by means of infrared NOAA AVHRR images. It allows us to locate the UTM coordinates of fires and calculate the affected areas. It is an operational procedure which does not require specialised personnel.

The detection of hotspots of less than one pixel is not dealt with by the algorithm in the same manner as is the detection of large scale fires. In both cases, analysis is carried out using the multispectral technique proposed by Dozier.

In order to study the reliability of the method, a comparison of the results will be made between the application of the algorithm in Spain and ground data. The detection thresholds can thus be adapted and improved. The possibility of deriving the thresholds from the data in the area surrounding the fire will be also taken into account.

Finally, it would be advisable to introduce atmospheric correction of the thermal images in the method and to study anomalous situations which may be due to the existence of smoke or large quantities of water vapour and which may modify the data used in the Dozier multispectral technique.

REFERENCES

Dozier J., 1981, A method for satellite identification of surface temperature fields of subpixel resolution. *Remote Sensing of Environment*, **11**:221-229.

Flannigan M.D. & Vonder Haar T. H., 1986, Forest fire monitoring using NOAA satellite AVHRR. *Canadian Journal of Forest Research*, **16**:975-982.

Kaufman Y. J., Tucker C. J.& Fung I, 1990, Remote sensing of biomass burning in the tropics. Journal of Geophysical Research, **95**:9927-9939.

Kidwell K.B. (ed), 1986, NOAA polar orbiter users guide. NOAA-NESDIS, National Climatic Data Center, Satellite Data Services Division, Washington, D.C.

Lee F. & Tag P.M, 1990, Improved detection of hotspots using the AVHRR 3.7-μm channel. *American Meteorological Society*, **71**(12):1722-1730.

López S., González F., Llop R. & Cuevas J.M., 1991, An evaluation of the utility of NOAA AVHRR images for monitoring forest fire risk in Spain. *International Journal of Remote Sensing*, **12**(9):1841-1851.

Matson K. & Dozier J., 1981, Identification of subresolution high temperature sources using a thermal IR sensor. *Photogrammetric Engineering and Remote Sensing*, **47**:1311-1318.

Matson M., Schneider S.R., Aldridge B. & Satchwell B., 1984, Fire detection using the Noaa-series satellites. US Department of Commerce, National Oceanic and Atmospheric Administration, National Environmental Satellite, Data and Information Service, NOAA Technical Report NESDIS 7, Washington, DC.

Miller N.,Chine E. & Howard S., 1983, Evaluation of AVHRR data to develop fire fuels information as an input to IAMS. Final Report. US Geological Survey.

Muirhead K. & Cracknell A.P., 1985, Straw burning over Great Britain detected by AVHRR. *International Journal of Remote Sensing*, **6**(5):827-833.

Paltridge G.W. & Barber J., 1988, Monitoring grassland dryness and fire potential in Australia with NOAA-AVHRR data. *Remote Sensing of Environment*, **25**:381-394.

Price J.C., 1984, Land surface temperature measurements from the split window channels of the NOAA 7 AVHRR. *Journal of Geophysical Research*, **89**(D5):7231-7237.

Robinson, J.M., 1991, Fire from space:global fire evaluation using infrared remote sensing. *International Journal of Remote Sensing*, **12**(1):3-24.