Remote Sensing in Transition, Goossens (ed.)
© 2004 Millpress, Rotterdam, ISBN 90 5966 007 2

A review of AVHRR-based fire susceptibility estimation methods

R. Lasaponara
IMAA-CNR, Tito Scalo, Potenza, Italy

T. Simoniello & V. Cuomo
DIFA, Università degli Studi della of Basilicata, Potenza, Italy
IMAA-CNR, Tito Scalo, Potenza, Italy

M. Macchiato
DSF, Università di Napoli "Federico II", Naples, Italy
INFM-unità di Napoli, Naples, Italy

Keywords: fire susceptibility, AVHRR, NDVI, thermal channels

ABSTRACT: The existing methods for fire susceptibility estimation (FSE) based on AVHRR data were applied in different regions of southern Italy. Their performances were evaluated by using a wide data sample of NOAA-12-14 summer imagery acquired from 1996 to 1999. The evaluation was performed by comparing the results obtained from the considered methods and the fire archives provided by the Italian National Forestry Service. The most satisfactory results were obtained from methods based on the cross analyses of NDVI (Normalized Difference Vegetation Index) with satellite-derived thermal data. In particular, the most satisfactory results were obtained when the two indicators are first classified separately and then combined in a single index.

1 INTRODUCTION

Yearly forest fires affect vast areas throughout the world and cause devastating damage so they are considered one of the most critical issues in global change. In order to limit such damage, fire agencies and fire brigades need to have effective decision support tools that are able to provide information updated on a short-term basis (daily predictions are usually required).

In this context, the use of satellite remote sensing has recently been considered very attractive given that a number of factors involved in FSE (land cover, vegetation condition) can be derived, at least partially, from satellite data. The characteristics (synoptic and repetitive views, spectral characteristics, and low costs) offered by imagers, such as NOAA-AVHRR, SPOT-Vegetation, and TERRA-MODIS appear particularly useful for the FSE. In fact, over the years, several satellite-based indicators have been developed for FSE most of which are based on AVHRR data (see, for example, reviews in Chuvieco, 1997; Chuvieco and Martìnez, 1999). Unfortunately, these indicators yield different results when applied to different ecosystems or geographic regions (see, for example, Lasaponara et al. 1999) and this creates confusion concerning their effectiveness. Nevertheless, efforts have been made, in order to integrate AVHRR-based parameters with other indices used for operational applications. Actually, the main unresolved problem is still the numerical evaluation of the improvement that can effectively be achieved by using only AVHRR-based parameters. This work is focused on the evaluation of performances obtained from the existing AVHRR-based FSE methods applied in the Mediterranean ecosystems of southern Italy.

2 THE FSE METHODS BASED ON AVHRR DATA

On the basis of the parameters used, the AVHRR-based FSE methods can be separated into the following three categories:

- FSE methods based on NDVI or NDVI derived-Indices
- FSE methods based on the cross analyses of AVHRR NDVI with satellite derived thermal data
- FSE methods based on AVHRR measurements and ground parameters (mainly meteorological measurements, such as air temperature, relative humidity, wind, etc.)

This work reviews and assesses methods that use only AVHRR-based measurements, so methods that use additional parameters (such as ground measurement) have not been included in this paper.

2.1 *FSE methods based on NDVI or NDVI-derived indices*

2.1.1 *Accumulated decrements of vegetation indices (Lopez* et al. *1991)*

Lopez's method consists of computing cumulated decrements of NDVI beginning from spring and lasting until the end of the summer. The calculation is performed by using the following relation computed over a 10 km by 5 km grid

$$ARND = \sum_{h=d1}^{dt} \frac{NDVI\ (idh+1) - NDVI\ (idh)}{NDVI\ (idh)} \qquad (1)$$

where ARND = cumulated relative NDVI decrement, NVDI daily images; id_h = the image of the date h; d_1, d_2…. = the date of available NDVI images.

Since this method uses daily NDVI values cloud cover and view-angle are minimized by selecting only the most suitable images for the study area. The fire susceptibility classification is performed by selecting pixels having negative values of ARND which are considered fire vulnerable.

2.1.2 *Accumulated slope of the NDVI curve (Illera* et al. *1996)*

Illera *et al.* (1996) have suggested the possibility of estimating forest fire susceptibility by using the NDVI temporal evolution beginning from spring and lasting up to the period in which the fire occurred. The calculation is performed by using the following relation computed over a 10 km by 10 km grid:

$$AS_n = \sum_{i=1}^{n} \frac{NDVI(t_i) - NDVI(t_{i-1})}{t_i - t_{i-1}} \qquad (2)$$

where As_n = accumulated slope of the temporal evolution of the NDVI curve.

This relation was applied only to forested areas, previously selected using the integral of the NDVI evolution curve for the same period.

Fire susceptibility classification is performed by selecting pixels having decrements in the As_n values greater than 0.01 considered fire vulnerable.

2.1.3 *Greenness indices*

Several authors (Eidenshink *et al.* 1990, Kogan *et al.* 1990, Burgan 1993) proposed the use of absolute Greenness indices (GRN_{abs} , see equation 3, Eidenshink *et al.* 1990, Kogan *et al.* 1990) or relative Greenness indices (GRN_{rel} , see equation 4, Burgan 1993) instead of NDVI.

$$GRN_{abs} = 100\ (ND_0 - ND_{min}) / ND_{max} \qquad (3)$$

where GRN_{abs} = absolute percent green; ND_0 = the observed NDVI for a given pixel; ND_{max} and ND_{min} are the maximum and the minimum NDVI observed on historical series of images for a given pixel.

$$GRN_{rel} = 100\ (ND_0 - ND_{min}) / (ND_{max} - ND_{min}) \qquad (4)$$

where GRN_{rel} = relative percent green; ND_0 = the observed NDVI for a given pixel; ND_{max} and ND_{min} the maximum and the minimum NDVI for the given pixel during the whole study period.

Experimental analyses tested both the GRN_{abs} (Dominiguez *et al*. 1995 Illera *et al*. 1997) and GRN_{rel} (Barlette, 2001). The GRN_{abs} exhibited low levels of correlation to ground measurements of fuel moisture content and to different indices of the Canadian Forest Danger Rating System (CFFDR) as well. Whereas, GRN_{rel} appeared to be not directly related to live fuel moisture content but strongly related to changes in fire occurrence.

2.2 *Methods based on the cross analysis of NDVI with thermal data*

Investigations performed by Nemani et al. (1993) have shown that very homogeneous areas exhibit a strong relationship between NDVI and Surface temperature as measured by thermal infrared emissions. For this reason, they proposed a spatial analysis based on the computation of the slope of TS/NDVI for the estimation of surface moisture status. The homogeneity of the target (unique biome, flat area) is a basic assumption of the method.

Some authors (Prosper-Laget *et al.* 1995; Illera *et al*, 1996, Alonso *et al*., 1996, Casanova *et al.* 1998) have developed methods for FSE substantially based on the approach devised by Nemani et al. (1993).

2.2.1 *Prosper-Laget et al. 1995*

Prosper-Laget *et al.* (1995) elaborated a forest risk index by dividing the bi-dimensional histogram (see equation 5) into five equal classes (quintiles).

$$NDVI = a * Ts + b \qquad (5)$$

The two parameters a and b have to be defined by using a statistical analysis on a time series considered significant for a given region.

The straight line that defines the risk is obtained by regressions on NDVI and Ts values observed on the cloud-free locations of the considered time series data. The threshold values are defined by selecting a given percentage of pixels on the distribution.

High (low) fire risk was deduced by applying the combination of high (low) surface temperature and low (high) NDVI values. Such an approach was applied to forest areas.

2.2.2 *Casanova et al. 1998*

Casanova et al. (1998) considered two indicators, (I) Vegetation Degradation and (II) Water Stress of

Vegetation. Such indicators are computed by using formula 7 and 8, respectively, over a 10 km by 10 km grid.

The Vegetation Degradation indicator is obtained by the following relation:

$$Ni = Dif_{average} - Ai\ f\ \sigma \tag{6}$$

where: Ni deduced risk class, i from 1 to 4; $Dif_{average} = Dif\ (NDVI_{today} - NDVI_{expected})$

$$NDVI_{expected} = a_i\ t^2 + b_i\ t + c_i \tag{7}$$

$NDVI_{today}$ is the measured NDVI, $NDVI_{expected}$ is the NDVI regression value of pixel "i", a_i, b_i, c_i coefficients are the specific regression coefficients of this pixel, and t is the time variable of the past day.
$A_1 = 1$, $A_2 = 2$, $A_3 = 2.5$, $A_4 = 3$; f = normalization factor; σ = standard deviation of the Dif. Magnitude
The second indicator is obtained by equation 8

$$Ts = m\ NDVI + n \tag{8}$$

Finally, four risk levels are defined by using the following four values for the parameter m (-30, -50, -70, -90).

The strong heterogeneity of our study areas (having mixed land cover and complex topography) makes the Casanova method as well as the slope of TS/NDVI not applicable to our test regions. This is due to the fact that the low accuracy of the computation performed in these conditions makes the estimations unreliable, as experienced by Nemani et al. (1993).

2.2.3 *Lasaponara et al. 2001*

On the basis of empirical investigations, Lasaponara et al. (1999, 2001, 2002) experienced that, during summer periods in Mediterranean ecosystems, the variations occurring in the NDVI (VDI, see equation 9) coupled with those in the AVHRR channel 3 middle-infrared data (TDI, see equation 10) provide a valuable indication on changes occurring in fire susceptibility. In particular, they experienced that:

- the use of channel 3 is able to provide more satisfactory results than those obtained using the TS or a single infrared channel 4 or 5;
- the maximum effectiveness was obtained when the two indicators are firstly classified separately and then combined in a single index (Lasaponara, 2002).

The NDVI temporal evolution was estimated from spring to the date of fire susceptibility map computation by revising the formula (2) proposed by Illera *et al.* (1996).

$$VDI = \sum_{i=1}^{n} \frac{NDVI(d_i) - NDVI(d_{i-1})}{d_i - d_{i-1}} \tag{9}$$

where VDI = Vegetation Danger Index; i = the image number in the considered series (from May to the day we compute the map); NDVI = daily NDVI value; di = the date of the given image.

The differences between Illera *et al.* (1996) procedure are:

- firstly, in order to perform estimation on a higher temporal resolution, daily NDVI was adopted instead of the maximum value composite images;
- secondly, in order to obtain a higher spatial resolution, formula 1 was computed at pixel level instead of smoothing over a 10 km by 10-km grid;
- thirdly, in order to obtain different degrees of fire susceptibility, the negative values of VDI were split into four equal classes instead of classifying them as dangerous areas having a decrement of VDI greater than 0.01.

The temporal evolution of the AVHRR infrared channel 3 was estimated pixel by pixel on cloud-free locations of several (5–6) images, previous to the day of map computation.

$$TDI = \sum_{i=1}^{n} \frac{T_j(d_{i-1}) - T_j(d_i)}{d_{i-1} - d_i} \tag{10}$$

where TDI = Thermal Danger Index; i = the image number in the considered series; d_i = the date of the given image; T_j = the AVHRR-derived surface temperature ch3 and ch4.

The different levels of fire susceptibility were obtained for both VDI and TDI by selecting a given percentage of the total investigated pixels, as follows:

2.5% Very High Class
10% High Class
20% Moderate Class

The rationale of such a classification is based on empirical observations. The analysis performed on fires occurring in the summer of 1996 have shown that the first (2.5%) and second (10%) percentage values are able to locate 85% of the fire events (40%, 45% respectively).

Finally, the Fire Danger Index was obtained by combining (following table 1) the information obtained from the NDVI-based parameters with those obtained from the AVHRR channel 3. High (low) fire danger was obtained by the combination of high (low) TDI and low (high) FDI values.

Table 1. Fire Danger Index combination matrix

	TDI			
VDI	**Very High**	**High**	**Moderate**	**Low**
Very High	Very High	Very High	High	Moderate
High	Very High	High	High	Moderate
Moderate	High	High	Moderate	Low
Low	Moderate	Moderate	Low	Low

3 INTER-COMPARISON OF AVHRR-BASED FSE METHODS IN THE MEDITERRANEAN ECOSYSTEMS OF SOUTHERN ITALY

3.1 *Study area*

The study was carried out in the Basilicata and Calabria Regions, in Southern Italy. These regions were selected principally for two reasons:

- They are classified as high-risk areas on a global scale (data provided by FAO, 2001) for the high number of fires, which generally occur during the dry season (from July to September).
- They exhibit *structural* differences. Fires usually burn small areas in Basilicata (less than 10 ha) whereas they affect vast areas in Calabria

The study areas have a Mediterranean climate with maximum precipitation during fall and winter and a minimum during the summer. The prevailing land covers are: agricultural areas, conifer stands (pine trees), deciduous stands (eucalyptus, chestnut trees, beech trees and oak trees), 'Mediterranean maquis' (small thickly packed trees, shrubs and bushes) as well as urban areas. The study area is strongly heterogeneous; it is characteried by a complex topography and mixed vegetation types. One AVHRR pixel is generally made up of a number of diverse cover types.

3.2 *Data set and pre-processing*

Satellite AVHRR data were acquired daily at the CNR-IMAA (Institute of Methodologies for Environmental Analysis) in Potenza, Italy. A time-series, from 1996 to 1999, was used for this study. Preprocessing steps are as follows:

- The calibration of AVHRR selected scenes was performed by applying the coefficients developed at NOAA-NESDIS.
- Nadir view selection. AVHRR has a wide scan angle (± 55°), which causes degradation in spatial resolution up to 2.5 x 7 km in the scene margins. Spatial degradation causes unreal decreases in the values of the observed parameters.
- Refinement navigation. All channels were geometrically registered in the Mercator projection, and a refinement navigation of LAC (Local Area Coverage) data was carried out with a margin of error less than 1 pixel. This is necessary in order to perform investigations at pixel scale, mainly for the estimation of the temporal dynamics of a given pixel.
- Refinement cloud detection. In order to remove cloudy pixels, we applied a threshold algorithm (Derrien, 1993) adapted to the study area and seasons.

3.3 *Application*

Since all the mentioned AVHRR-based parameters (see section 2) do not provide any measurements of vegetation water content, we chose to compare the results from the considered methods to the real fires occurring in the study areas in the summers 1995 to 1999. For a given date, fire events and burned areas were geo-referenced and superimposed on AVHRR-based fire susceptibility maps. In order to assess the performances of the considered methods, the following indices have been defined:

- S_{FS} = fire susceptibility surface / investigated surface
- S_{BS} = burned surface / fire susceptibility surface

The S_{FS} performance index is computed from the ratio between surfaces classified as fire vulnerable and the total investigated area. The S_{BS} performance index provides the ratio between pixels affected by fire and areas classified as fire vulnerable according to the current method.

In the study regions (mainly in Basilicata), it is expected that the surfaces classified as fire vulnerable should be a small percentage of the total investigated areas.

Table 2 shows the results obtained from the considered methods. Please, note that the results for the summer of 1997 are not shown because 90% of the investigated AVHRR scenes (110) are unusable for the study areas due to cloud cover and off nadir view.

Table 2. Results from the evaluation tests performed over 365 real fires.

	S_{BS}	S_{FS}
ARND by Lopez et al (1991)	90%	70%
AS_n by Illera et al. (1996)	73%	46%
GRN_{rel} by Barlette (2001)	61%	23%
Prosper-Laget et al. (1995)	18%	1.80%
Lasaponara et al.(2001)	82%	4.50%

S_{FS} = fire susceptibility surface / investigated surface;
S_{BS} = burned surface / fire susceptibility surface.

These experimental analyses have shown that FSE method based on NDVI (or NDVI-derived parameters) tend to classify large areas as fire vulnerable, whereas valid improvements are achieved by using the cross analysis of NDVI with thermal channels. In particular:

Among the methods based on NDVI or NDVI-derived indices we found that:

- The ARND appears to provide the most unsatisfactory results. The rate of predicted fires is 90%, but this is due to the fact that it tends to select as fire vulnerable around 70% of the total investigated surface. Such information cannot be useful in operational conditions.
- The AS_n appears to work better than ARND but this is due to the fact that, as suggested by the authors, the ARND has been applied to the whole study area, whereas AS_n has only been applied to forests. Nevertheless, the grid suggested by the authors does not appear the most adequate for the study area since the forests are usually less than the considered cells.
- The GRN_{rel} are applied to our study area by using a long time series 1985 to 1999 of NDVI maps which were elaborated as in Cuomo et al. (2001). Results from the GRN_{rel} appear the most satisfactory. The improved performance is due to the methodological approach (based on the historical analysis of a long time series) and also on the scale factor. In fact, for the GRN_{rel} the computations are performed on a pixel scale basis, which appears the most adequate for our study area.

Concerning the FSE methods based on the cross analyses of NDVI with thermal data, the most satisfactory results were obtained when the two indicators are firstly classified separately and then combined in a single index (as in Lasaponara et al. 2001). This allows a valid reduction of the number of pixels classified as fire vulnerable compared with methods that apply a joined classification of NDVI and Ts (as in Prosper-Laget et al., 1994; and Casanova et al., 1998). Finally, the use of the AVHRR channel 3 (thermal data) proved to be more effective than TS.

4 CONCLUSIONS

The AVHRR based fire susceptibility classification proved to be highly selective and this demonstrates the high potential capabilities of satellite-based techniques in the FSE. Our evaluations are a valuable support for:

- FSE based on data from new sensors, such as Terra-MODIS, Envisat-AATSR, that provide repetition rates and wave bands similar to those of NOAA-AVHRR. Moreover, significant improvements in FSE are expected from data from these new sensors since they provide measurements in spectral bands that appear particularly sensitive to moisture content.
- the assessment of how satellite-based parameters can be used profitably to improve the estimation of fire susceptibility in operational applications.

Our findings can be directly extended to other Mediterranean-like ecosystems.

ACKNOWLEDGEMENTS

The authors wish to thank Davide Pontani of the Italian National Forestry Service for providing fire data, which has made this study possible. This work has been funded by the MIUR within the framework of PON project (2002- 2005).

REFERENCES

Burgan, R.E., Andrews, P.L., Bradshaw, L.S., Chase, C.H., Hartford, R.A. & Latham, D.J. 1997. *Current status of the wildland fire Assessment System (WFAS), Fire management Notes,* 57, 14-17.

Burgan, R.E. 1998. *Revisions to the 1978 National Fire-danger rating System. Res. Pap. SE- 273. Asheville, NC: U.S.D.A, Forest Service, Southern Forest Experiment station*: 39.

Casanova, J.L., Calle, A. & Gonzàlez-Alonso, F. 1998. *A forest fire risk assessment obtained in real time by means of NOAA satellite images. III International Conference on Forest Fire Research'98, 15-20 November 1998 (Coimbra: ADAI)*: 1169-1179.

Chuvieco, E., 1997. *A review of remote sensing methods for the study of large wildland fires: (Megafires project ENV-CT96-0256). E. Chuvieco (Editor), Universidad de Alcala, Spain*: 3-5.

Chuvieco, E., and Martìnez, J. 1999. *Review of fire risk evaluation techniques: estimation of fuel moisture content. In Proceedings of International Symposium Forest fires: needs and innovations. CINAR S. A., Athens, Greece*: 63-72.

Cuomo, V., Lanfredi, M., Lasaponara, R., Macchiato, M. F. & Simoniello, T., 2001. *Detection of inter-annual variation of vegetation in middle and southern Italy during 1985-1999 with 1 km NOAA AVHRR. Journal of Geophysical Research,* Vol. 106 (No. D16): 17863-17876.

Derrien, M., Faki, B., Harang, L., Legleau, H., Noyalet, A., Pochic, D. & Saorouni, A. 1993. *Automatic cloud detection applied NOAA-11/AVHRR imagery. Remote Sens. Environ*, Vol. 46: 246-267.

Eidenshink, J.C., Burgan, R.E. & Haas, R.H. 1990. *Monitoring fire fuels condition by using time series composites of Advanced Very High Resolution Radiometer (AVHRR) data. Proc. Resource Technology 90, ASPRS, Washington, D. C.*: 68-82.

FAO, 2001. *Global forest fire assessment 1990-2000. Forest Resources Assessment Programme, working paper n.55, http://www.fao.org:80/forestry/fo/fra/docs/Wp55_eng.pdf.*

Gonzàlez-Alonso, F., Cuevas, J.M., Casanova, J.L., Calle, A., & Illera, P. 1997. *A forest fire risk assessment using NOAA AVHRR images in the Valencia area, eastern Spain. Int. J. Remote Sens.,*Vol. 18: 2201-2207.

Illera, P., Fernandez, A. & Delgado, A.J. 1996. *Temporal evolution of the NDVI as an indicator of forest fire danger. Int. J. Remote Sens.,*Vol. 17: 1093 - 1105.

Kogan, F.N. 1990. *Remote sensing of weather impacts on vegetation in nonhomogeneous areas. . Int. J. Remote Sens.,*Vol. 11: 1405-1419.

Lasaponara, R., Cuomo, V., Tramutoli, V., Pergola, N., Pietrapertosa, C. & Simoniello, T. 1999. *Forest fire danger estimation in the Italian Peninsula based on the integration of satellite AVHRR data and topographic factors Remote Sensing for Earth Science, Ocean, and Sea Ice Applications. SPIE, Bellingham, edited by G. Cecchi, E.T. Engman, and E. Zilioli USA,*Vol. 3868: 241-252.

Lasaponara, R., Cuomo, V., Macchiato, M.F. & Simoniello, T. 2001. *Dynamic Estimation of fire forecasting based on AVHRR data, 3rd International workshop Remote sensing and GIS applications to forest fire management- new methods and sensors, EARSeL, Paris May 2001 edited by Chuvieco and Martin* : 49-54.

Lopez, S., Gonzàlez-Alonso, F., Llop, R. & Cuevas, J.M. 1991. *An evaluation of the utility of NOAA AVHRR images for monitoring forest fire risk in Spain. Int. J. Remote Sens.,*Vol. 12: 1841-1851.

Nemani, R.R., Pierce, L., Running, S.W. & Goward, S. 1993. *Developing satellite–derived estimates of surface moisture status. Journal of Applied Meteorology,* Vol. 32: 548-557.

Prosper-Laget, V., Douguedroit, A. & Guinot, J.P. 1994. *A satellite index of forest fires occurrence risk in summer in the Mediterranean area. II Int. Conf. Forest Fire Research., Coimbra: ADAI, Portugal,* Vol. 2: 637-646.