FOREST FIRE DETECTION AND MONITORING BY MEANS OF AN INTEGRATED MODIS-MSG SYSTEM

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This work presents the MSG-SEVIRI sensor's capacity for the detection of forest fires and the subsequent fire monitoring. The Remote Sensing Laboratory of the University of Valladolid has a receiver system in real time as well as an operating fire detection system, also in real time, that spreads results via the Internet. Here are shown some concrete results and the methodology of the processes involved is explained.

Introduction

The study of forest fires through remote sensing techniques has been limited to the cartography of burned areas in those cases where real time work is required, and to the assessment of the spreading risk when being operative is required. On the other hand, fire detection is a necessity which won't be solved until geostationary satellites prove their capacity to detect small fires and show their usefulness in providing early alert warnings, which will be really difficult considering the difficulty of building high spatial resolution thermal sensors. In this way, simulations aimed at detecting the minimum detectable area according to the temperature have been carried out on GOES and MSG [1]. In the latter's case and for our latitudes, a size larger than 1.5 ha. is necessary for a fire of 600 K to be detected, and this without including the effects of atmospheric attenuation.

On the other hand, the establishment of an early fire alert system through polar satellites, which would solve the spatial resolution problem, has already been considered in the well-known FUEGO project financed by ESA. This project tries to put 12 polar satellites in three orbital planes so that they can work jointly and provide approximately a 15-minute time resolution. The most relevant conclusion with respect to the use currently made of fire detection through spatial sensors is that so far it's been used for the elaboration of fire occurrence mapping and the obtaining of statistical results.

With respect to the sensors used to carry out fire detection, the most important one without doubt has been the NOAA-AVHRR sensor thanks to its higher time resolution and to the type of sensors it has. Detection through AVHRR has been developed through different algorithms that can be classified into two types: algorithms based on fixed thresholds and contextual algorithms, whose parameters have been adapted to the different zones of study. This sensor's low spatial resolution, 1 km^2, has allowed us to study at a sub-pixel level through the application of *Dozier's* methodology [2]. From this methodology, it is possible to determine simultaneously the fire's temperature and the fraction that is burning. In spite of its limitations, the AVHRR must be used as a comparative reference for later sensors such as MODIS.

The appearance of the MODIS sensor in 1999 on the TERRA and AQUA stations with its 36 spectral bands has improved detection capacities tremendously. In this way, the algorithms based on the AVHRR have been adapted and improved for the MODIS [3].

The appearance of the experimental satellite BIRD designed by the DLR, from Germany, and whose aim is fire detection makes us think that the search for an operative early warning spatial system will be a reality not very far into the future [4].

The Remote Sensing Laboratory of the University of Valladolid has a receiver antennae of MSG images that has been operating since May 2004. That's why, the 2004 summer fire campaign has been prepared to spread fire detection and monitoring results in real time using the SEVIRI sensor. The objective of this work is to analyze the fire detection capabilities and determine, from the sub-pixel analysis, the fire's energetic intensity. This parameter is related to the fire's temperature and the simultaneous area that is burning. This factor is expected to be an excellent indicator of a forest fire's destructive power and severity so that approximate qualitative estimations on the damage caused can be carried out.

Fire detection

Fire detection using remote sensing techniques is not a particularly difficult task except for, as it is logical, the possibilities of the sensor used in relation with the minimum size detected and according to the fire's effective temperature. The detection methods used on other sensors that have been the reference are sometimes based on physical models. However, the experimental statistical models have shown better results and are easier to apply. Thus, the algorithms based on thresholds have worked on the AVHRR sensor [5] and the contextual models have been operating on AVHRR and MODIS [3, 6, 7]. However, the difficulty of the validity of the detection results lies in the quality of the data, that's is, the appropriate filtering of false alarms since the errors occurred in almost every model are errors of commission.

Methodology

In the case of the SEVIRI sensor, our laboratory has started to get results in real time through the application of a method based on the contextual analysis modified through the time conditions of permanence of the fire. The aim is to spread this information via the Internet with added information concerning the toponymy added value in the events.

The methodology followed for the present study is based on the use of two thermal spectral bands situated in the region of 3.9 and 10.8 μm respectively. A contextual analysis is carried out on them through a spatial matrix of N×N pixels, establishing the required statistical parameters, mean value and standard deviation. The detection test consists, finally, of assigning as affected pixel the one that fulfils the following:

$$T_{3.9} > \mu_{3.9} + f \cdot \sigma_{3.9}$$

$$T_{3.9} - T_{10.8} > \mu_{dif} + f \cdot \sigma_{dif}$$

where μ and σ are the mean value and the standard deviation in each channel respectively. Although the contextual algorithm has been widely used for other sensors, there still aren't any established values for the size of the matrix of analysis applicable to SEVIRI and the statistical factor *f*. A large interval of values for fires of different sizes have been studied throughout the summer of 2004 with the aim of obtaining the detection without the inclusion of a large number of false alarms near the clouds. Finally, our system is working with three different values which show three different levels of probability in the detected fire.

With respect to the filtering of points of analysis with a cloudy cover, the band of 10.8 μm has been used in order to get rid of low temperature points.

It must be pointed out that the algorithm described was applied on the present image received in real time and both on the present image and the one immediately before for the establishment of the statistical parameters. In none of the cases were there noticeable differences, neither in the detection results nor in the elimination of false alarms. However, an analysis carried out on a larger variety of fire sizes will establish exhaustively which of the contextual algorithms, spatial or time algorithm, will be the most appropriate one.

In spite of the fact that the methodology described provided satisfactory results in the detection, the problem of false alarms continued. That's why, a consolidation criterion was later applied with respect to the points obtained. A previous analysis of the points affected was carried out so that fires were considered as such when they persisted from the previous image in the same exact position or moved to one of the 8 adjacent pixels.

Results

Fig.1 shows the graphic results corresponding to the detection. In this case, only the contextual algorithm was applied without the subsequent time consolidation. This image has been chosen since it shows the most serious fire, which occurred in Spain during the summer of 2003. The algorithm was applied consecutively and uninterruptedly during the two and a half days during which the advance of the fire took place and hot spots were found during the whole period. The fire finally devastated 27000 ha. in the province of Huelva (Spain). Other fires that took place simultaneously in Galicia and Portugal are also shown. All the spots shown here have been validated through the MODIS results in a coinciding orbital pass.

Fire monitoring using MSG

The real usefulness of remote sensing in the early detection of fires will take place when the time resolution of the sensors implied is around 15 minutes or less. At present, this characteristic is only available in the geostationary satellites, but they have the problem of their low spatial resolution.

After the detection, the problem of the analysis of the fire parameters such as the fire temperature, the area affected by it and the intensity released, is brought up. This analysis scheme is what we have comprised under the name of fire monitoring and we have applied it to the large fires of Portugal during the summer of 2003. These fires analyzed affected a total area of 400 000 ha and went over a period of close to 10 days.

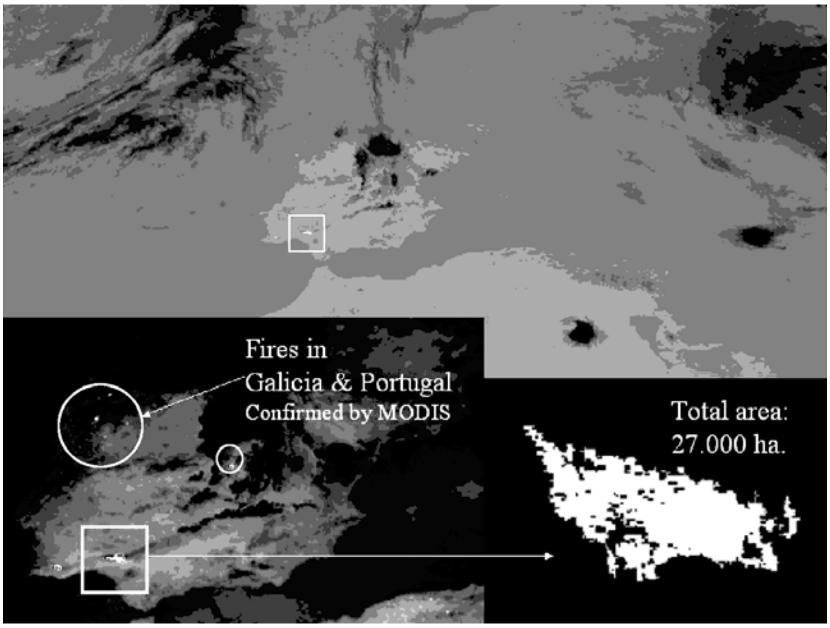

Fig.1. Results of detection algorithm in Spain & Portugal.

Methodology

The fire detection work has been widely documented for most sensors. In the case of MODIS [3, 8], for the BIRD case [4, 9] and for the SEVIRI case as an extension of the algorithms for GOES [10]. The next process to be applied after the detection of hot spots is that leading to the fixing of the fire's parameters, that is, the fire's temperature, the area taken up by the burning flame and finally the energy intensity. Two levels of analysis have been distinguished to fix these parameters. First, the analysis at pixel level, where all the pixels affected will be studied and characterized. On the other hand, the analysis at cluster level.

By cluster it is understood a group of pixels affected by the fire and in contact with each other. In the clusters case, the parameters are the cluster's flame area, the cluster's pondered temperature and the total intensity provided by all the pixels affected.

In order to carry out this analysis, we have applied first the technique suggested by *Dozier* [2, 11] based on the solving of the following system of equations proposed for bands MIR and TIR:

$$L_i(T_i)=\tau_i\cdot\left\lfloor fB_i(T_f)+(1-f)B_i(T_{black})\right\rfloor ,$$

where the sub-index i refers to the two MIR and TIR bands, f is the pixel's fraction which is on fire, T_f is the fire's temperature, T_{back} the temperature of the surface non-affected by the fire and τ_i the atmospheric transmittance in each of the two bands to which this equation refers. The resolution of the two former equations system has been done through numerical methods since they are not explicit equations.

The problem in the application of the former equations lies in the introduction of the appropriate surface temperature value. This value is not known and it must be calculated through the mean of the surrounding non-affected pixels. On the other hand, small errors committed when fixing this variable imply strong variations in the establishment of the fire's temperature. Simulations on a real, programmed and controlled fire have been carried out in order to reach some conclusions.

Fig.2 represents the variation of the fire's temperature obtained after *Dozier's* application according to different suggested values for the surface's temperature. Thus, it can be noticed that a 10-degree variation in the surface's temperature means a 80-degree variations in the fire's temperature since the function that relates them is a 2-grade polynomial. In the same figure, the same variation of the fire's intensity obtained is represented. This simulation has been carried out on MODIS pixels.

For the reasons mentioned above, we have applied the methodology suggested by *Giglio & Kendall* [7]. They suggest introducing the surrounding pixels' radiance so that the atmospheric effects can be taken into account as well as the small surface's solar reflective contribution in day images. This is summarized in the following system of equations:

$$L_i=\tau_i\cdot p\cdot B(\lambda_i,T_f)+(1-p)\cdot L_{background,i}+p\cdot L_{atmos,i} .$$

The subsequent fixing of the fire's energy intensity has been carried out through the application of *Stefan-Boltzmann's* equation using the fire's area and temperature resulting from the former system of equations.

The fire analyzed was found to take up more than one pixel. That's why the sub-pixel analysis was done to all K pixels implied, obtaining for each of them a $T_{f,k}$ and a surface S_k. The final surface used for the estimation of the fire's intensity and the fire's approximate and pondered temperature T_f were determined through the expressions:

$$T_f = \frac{\sum_k T_{f,k} \cdot S_k}{S}, S = \sum_k S_k \ .$$

This is what we have called analysis by cluster, understanding by such a group of pixels affected by a fire, which are in contact through some of their sides.

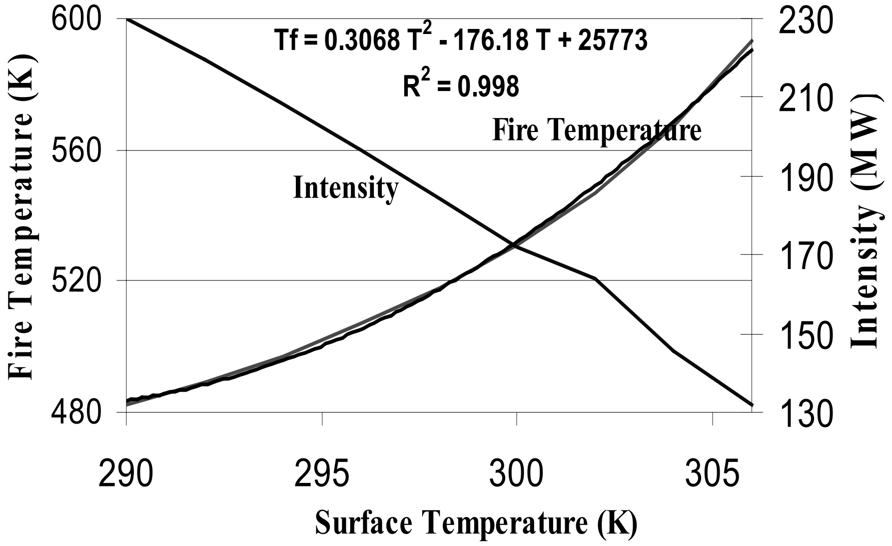

Fig.2. Fire Temperature and Fire intensity versus background temperature as results from original *Dozier* application.

Results

Since the fires we have been describing are large-sized fires, we have decided to carry out the monitoring analysis using the SEVIRI sensor. This sensor has 12 spectral bands, two of which are operative in the same wavelengths than those of MIR and TIR bands in the AVHRR, so that they are useful for the methodology stated. However, these bands have a spatial resolution of 3 km in the nadir, which means approximately 3×4.5 km^2 for the Iberian Peninsula's latitudes. In spite of being large pixels, slight increases of the radiance in the MIR show the existence of zones burning inside. We also have another basic sampling tool: the availability of an image every 15 minutes to carry out the evolution of the fire's intensity.

This sensor proves its usefulness thanks to the possibility of evaluating the fire's energy as it moves. Fig.3 is very clear. In it, these evolutions are represented for the fire's advancing line and for the decreasing line between 12:00 and 16:00 GMT of 3-rd August, in the summer of 2003. Analyses were carried out on pixels and clusters being the 0.3 ha with flame the minimum size detected.

The above mentioned figure shows the study of one of the largest fires in the area analyzed. As can be noticed, a cluster has been chosen and an analysis of the intensity of the pixels affected has been carried out on it. It was found that the advance of the fire takes place in the left part whereas the right part is the extinction zone. This general view over one of the snapshot images can be corroborated when we analyze the time evolution, between 12:00 and 16:00 GMT, of the obtained intensity parameter. Without doubt, this is the main use of a sensor whose images have a time resolution of 15 minutes.

Conclusion

The MSG sensor has shown its capacity as an earth observer sensor that provides relevant information in the search and study of large forest fires. The following conclusions relative to each of the themes studied, detection and monitoring can be reached.

With respect to the detection, this is the most delicate task since although the detection is not a problem per se, it has the difficulty of false alarms. The contextual procedure is reliable in general terms but the final statistical parameters provide a large number of errors. For this reason, it is necessary the time filter proposed which is based on the consolidation through the observation of the previous image. The added problem is that the time resolution decreases to 30 minutes because of the waiting for the consolidation test.

The monitoring phase applied after the detection provides very useful results from a qualitative point of view. The intensity values obtained cannot be compared with other sensors, such as MODIS, due to its different spatial resolution. However, we find coincidences in the hottest zones of the fire so that the values obtained are useful for the study of the subsequent evolution of the fire, as Fig.4 shows.

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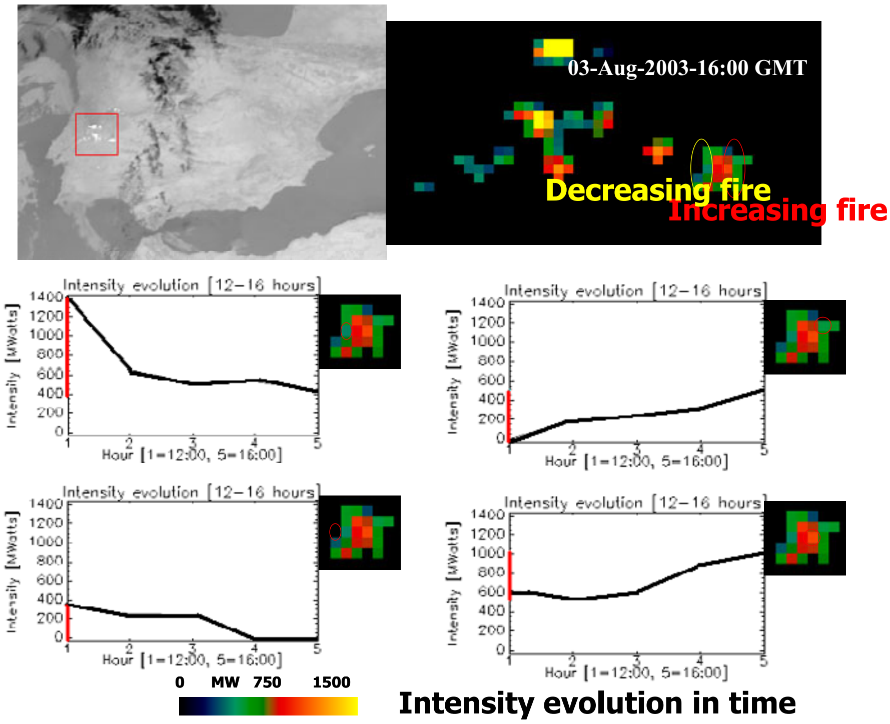

Fig.3. Intensity evolution, in Mwatts, for different pixels affected by fire.

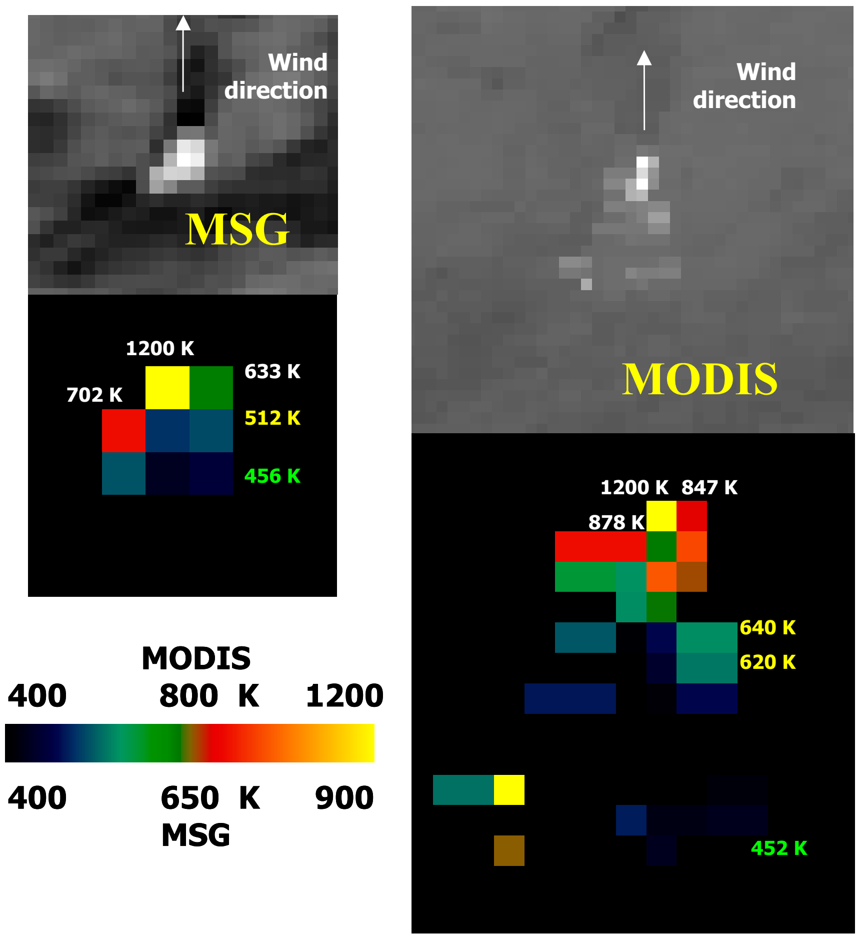

Fig.4. A comparison of the same fire, between MODIS and MSG sensors.
There is coincidence about the front line.