Performances assessment of the SFIDE algorithm devoted to early fire detection by using SEVIRI/MSG images

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Abstract

Forest fires represent the main cause of forest degradation in Italy and in the Mediterranean area countries. This phenomenon, progressively increasing, reached an average of 11000 fires per year in the period 1990-2000 with the destruction of 553,000 ha of vegetated areas in the Italian peninsula. In previous papers the capability to detect fires much smaller than the pixel size (4.0 km at middle latitude) using the SEVIRI (Spinning Enhanced Visible and Infrared Imager) sensor on board of the geostationary satellite MSG (Meteosat Second Generation) has been demonstrated. Due to the reduced spatial resolution of this sensor its capability to provide a prompt fire detection suitable to support operational firefighting activities is still under study.

The Centro di Ricerca Progetto San Marco (CRPSM) is acquiring SEVIRI data since 2003 and has developed an innovative technique (SFIDE, System for Fires Detection), based on the exploitation of both the classical MIR and TIR spectral bands and the high observation frequency (15 min), to counteract the low spatial resolution characterizing such a sensor. The present paper aims to present the results obtained applying this technique and, at the same time, to confirm the applicability of the SEVIRI sensor as an instrument suitable to be employed in an operational system of early fire detection. For this purpose, an automatic system of early fire detection, based on the SEVIRI/MSG data, has been developed and tested in the Sardinian region during the month of August 2006. The validation of the results comprises the promptness of the detections (compared with the common ground based warnings), the errors of the geo-location and the accuracy of the sizes estimate of the hot-spots.

The assessment of the performances of the system has been obtained mainly comparing its results with those obtainable from higher resolution sun-synchronous sensors data (MODIS, MODerate resolution Imaging Spectro-radiometer) and by using the Italian Forest Corps reports.

Introduction

In previous papers we introduced a technique to detect small fires exploiting the high temporal frequency guaranteed by SEVIRI sensor on board of the geostationary satellite MSG (Meteosat Second Generation) and we tried to assess the detection limits reachable with our algorithm by comparing the SEVIRI fire products with those provided by a higher spatial resolution sensor like MODIS (Laneve and others 2006a; Laneve and others 2006b).

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The innovation, with respect to other forest fires detection methods based on geostationary or low orbit satellites, represented by the SFIDE algorithm, of which some results will be described herein, consists in the attempt to exploit the quasi-continuous Earth observation that SEVIRI provides to set up a wildfire automatic early detection system. The responses we are trying to provide in this paper regard:
the promptness of the detection, with respect to the standard technique based on the ground observation (fire guards);
the possibility, in presence of several simultaneous fires, to provide, the decision makers with an objective element useful to optimise limited resources, supplying information to set the intervention priorities, on the base of the dynamics and size of each detected fire.
The detection algorithm, applied to SEVIRI images, works in a way to exploit the high temporal frequency of the images acquisition and allows to reveal, at Italian latitudes, fires covering an area of the order of 0.1 ha. Thus such an algorithm, even if based on the same spectral bands (the MIR, Middle InfraRed and TIR, Thermal InfraRed) of the low earth orbit sensors, results substantially different from the algorithms usually applied to these. Naturally the minimum detectable size depends mostly on the burning temperature of the fire. This paper is devoted to show the performances of the algorithm developed by CRPSM and presented in a couple of previous papers by comparing its results with those obtainable from higher resolution sun-synchronous sensors data (MODIS) and by using the Italian Forest Corps (Corpo Forestale dello Stato, CFS) reports period covering the month of August 2006.
The activity of CRPSM in this field is drove by the interest of ASI (Italian Space Agency) to develop a system, based on satellite data, able to support firefighting in real time.
Several studies have clearly assessed the capability of suitable algorithms (Prince and others 1991; Prins and others 2001; Lee and others 1990, Flasse and others 1996) to detect fires of very small size, compared with the satellite image pixel size, using the brightness temperature measured in the MIR (Middle InfraRed) and TIR (Thermal InfraRed) spectral channels. However the limited temporal revisit frequency of low earth orbit (LEO) satellites has prevented, up to now, the possibility of using satellite observations as a support to the real time counteraction of fire events. For this reason, given the improved characteristics of the SEVIRI sensor, notwithstanding its limited spatial resolution, it is interesting to explore the actual applicability of the MSG geostationary satellite, that is able to guarantee a 15 min. images temporal resolution.
The key parameter in detecting a fire, the so-called "*active fire signal*", is represented by an increment of the radiance in the range between 3 to 5 μm, with respect to the surrounding area as a consequence of the typical burning temperature of a fire.
Presently, fires monitoring is performed by using daily LEO orbit satellite data like these provided by NOAA/AVHRR (for the Southern Europe monitoring, by the SAI/JRC World Fire Web Initiative) (Flasse and others 1996) or the ERS/ATSR-2 (Along Track Scanning Radiometer) (by the European Space Agency, ESA) (Arino and others 1999) or by the TRMM/VIRS (Tropical Rainfall Measuring Mission) (to study fires at latitudes lower than 40° N) (Giglio and others 2000a).
The Rapid Response System (RRS) has been developed by NASA to provide rapid access to Terra and Aqua/MODIS data globally, with emphasis on active fire data (Giglio and others 2000b).

The AFIS (Advanced Fire Information Service) project represents the first system for near real time satellite based fire monitoring in Africa. It relies on the exploitation of MODIS and SEVIRI images to detect fires which can cause flashovers on the power transmission lines of South Africa.

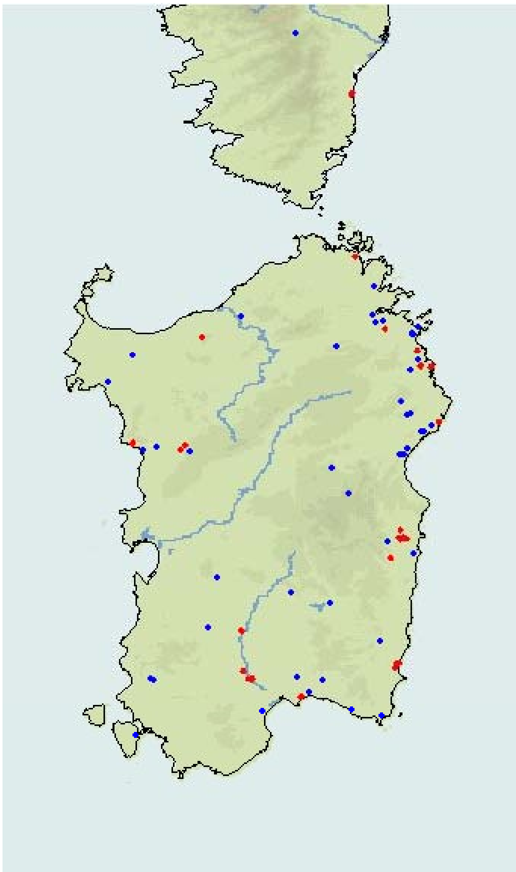

Figure 1. A) Distribution of the fires, as detected by both RRS using MODIS and SFIDE using MSG (red spots), and by SFIDE only (blue spots), during August 2006 on the Sardinia island.

Data and Method

The SEVIRI 15 min. temporal resolution data used in the analysis have been directly acquired at CRPSM in Rome. MODIS images have been downloaded by NASA website. The CFS provided the list of fires compiled for the Sardinia island during August 2006. In order to counteract the reduced spatial resolution (4.5 km at Italian latitude) of SEVIRI images, maintaining accurate fire detection capabilities, in terms of fire size and reduced false alarm, a new algorithm, called SFIDE (System for Fire Detection), based on the same spectral bands exploited by the classical technique (absolute or contextual threshold), has been applied. This algorithm (Laneve and others 2006a) exploits the high observation frequency of the SEVIRI sensor, by using a comparison between the simulated 15 min pixel surface temperature variation, and the actual variation measured using SEVIRI data in the channel 4 (around 4 μm). In this way, if all the terms causing a surface brightness temperature variation are correctly simulated the only limitation in the minimum size of the detectable fire is related to the NEΔT associated with the detector measurement (lower than 0.2 K) in the channel 4.

These minima sizes are, of course, only theoretically obtainable when the temporal variation of the surface temperature is perfectly simulated. To approximate this detection limit the surface emissivity, atmospheric conditions, solar illumination condition variation, etc. must be taken into account and correctly simulated. In the following paragraph the results obtained by comparing SEVIRI imagery based fires detection techniques, MODIS based fires detection and reports from CFS, are reported. The comparison covers a period of a month, corresponding to August 2006. It allows to evaluate the performances provided by the SEVIRI, when a fire detection algorithm, based on a change detection method, is adopted.

Results

First of all, the results, provided by the algorithm developed at CRPSM applied to SEVIRI images, are compared with those obtained by the Rapid Response System (RRS) based on the MODIS images. Figure 1 shows the distribution of fires, detected

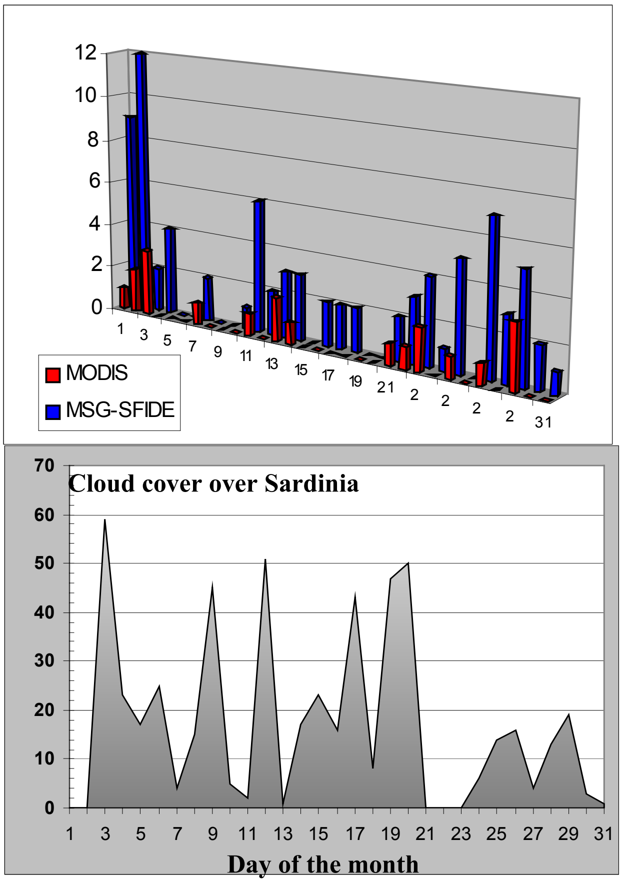

Figure 2. A) Distribution, day by day, of the fires, as detected by RRS using MODIS and by SFIDE using MSG during August 2006 on the Sardinia island. B) Daily Clouds coverage.

during August 2006, as given by the RRS using MODIS Terra and Aqua images and the same distribution as estimate by applying the SFIDE algorithm to the SEVIRI images. In particular the red dots show the fires detected by both approaches and the blue dots these detected only by SFIDE.

As expected, due to the high temporal frequency of the SEVIRI images, the number of fires detected by the SFIDE algorithm is much larger than that provided by RRS (Fig. 2A). Anyway, this result is not obvious since the scarce spatial resolution of geostationary sensor poses, in principle, some concerns on the minimum size of the detectable fires. In fact, the reported number represents hot spots involving different pixels. In other words each fire has been counted only once, when it appears for the first time on the image. The MSG-SFIDE algorithm has detected all the fires detected by MODIS also.

The daily variability in the number of detected fires depends mostly by the change in the clouds coverage of the region, Fig. 2B.

The comparison between the positions of the fires detected by using MODIS and SEVIRI images allows to assess the accuracy in the geo-location of the MSG based fires. Fig. 3 shows the distribution of the fires detected in August, in Sardinia, in geographical coordinates. The blue squares represent the SEVIRI pixels and the red squares the MODIS ones. In average we find a mean error between the position provided by the two sensors of 0.014 deg (1.23 km) in longitude and 0.0145 deg (1.56 km) in latitude. These values are compatible with the limits imposed by the SEVIRI pixel sizes, even if, in some cases, this limit can be overcame using a sub-pixel approach, that will be attempted in the near future.

With reference to the fire sizes we can say, according to Fig. 4, that SEVIRI, as possibly expected, tends in general to overestimate the dimensions of a 20% or less, with respect to MODIS. Regarding the temperature of the fires, also this parameter results generally overestimate by SEVIRI of a 20%. Both fire burning temperature and instantaneous sizes are computed using the classical Dozier (Dozier 1981) approach.

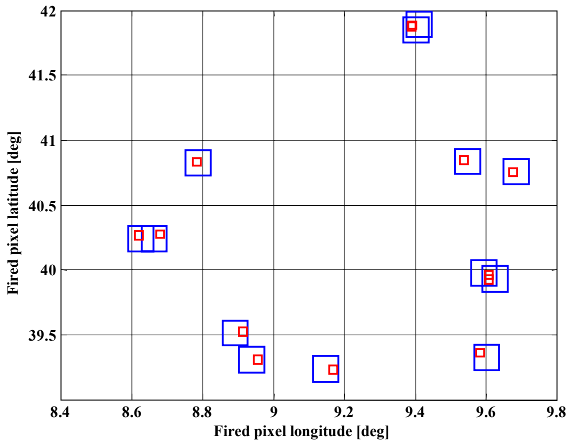

Figure 3 - Geographic distribution of the major fires detected during the month of August 2006 by using RSS (on MODIS) and SFIDE (on SEVIRI).

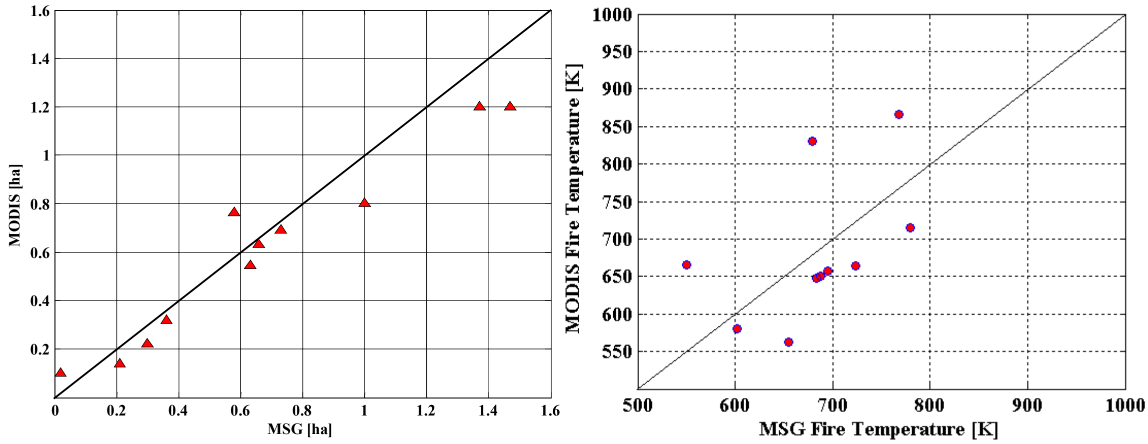

Figure 4 -Comparison between sizes and temperatures of the major fires detected during August 2006 obtained applying the Dozier relationship (Dozier 1981).

Table 1 - Example of the report on fires provided by Italian CFS**.**

Date	Municipality	Place	Time	UTM Long	UTM Lat	Forest	No Forest	Total
01-aug-06	Telti	Suliana	12.10	529200	4524700	0,00	2,50	2,50
01-aug-06	Sorso	Lu Paronaggiu	12.27	466300	4519300	0,00	3,13	3,13
01-aug-06	Serramanna	Bia Serramanna	13.20	494500	4366900	0,00	5,23	5,23
01-aug-06	Macomer	Tamara	13.30	478900	4458000	0,50	3,50	4,00
01-aug-06	Sindia	N.Ghe Nelu	13.40	468900	4459200	0,00	10,00	10,00
01-aug-06	San Vito	Baccu Cannas	13.55	546600	4367500	1,00	2,00	3,00
01-aug-06	Sassari	Badde Rebuddu - Badde Funtana	15.15	452800	4507000	0,00	6,57	6,57
01-aug-06	Olbia	Suiles	16.16	547500	4534500	5,00	0,00	5,00
01-aug-06	Olbia	Muddizza Piana	16.24	535200	4533500	50,00	0,00	50,00
01-aug-06	Lode'	Montetundu-Vallai	22.15	500000	4400000	5,25	11,50	16,75
01-aug-06	Posada	Orvile	22.17	562300	4501100	12,00	28,00	40,00

The comparison with the data acquired on the ground by the group of the CFS operating in Sardinia is based on a report, like the one shown in Tab. 1. The information contained in such report regard: the municipality interested, the delivered time of alarm, the UTM coordinates of the fire starting point, type of vegetation involved and the final sizes of the burned area, when the fire has been extinguished. Based on the information contained in such a report we can compare, in principle, the promptness of the satellite based detection, the accuracy of the geolocation, the number of undetected fires. The analysis herein described has been restricted to the fires that, at the end, have burned, at least, a surface of 2 ha.

Let us start with the analysis of the sensitivity of the system to fires. Figure 5 reports the percentage of fires detected by SFIDE compared with the fires reported in the CFS report. As it can be seen the 63% of the fires requiring a fighting intervention have been detected. If we analyse better the characteristics of the 37% of undetected fires, we can see (Fig. 6) that in several cases (41%) the area interested by the fire was cloudy, then the detection from satellite can results very difficult.

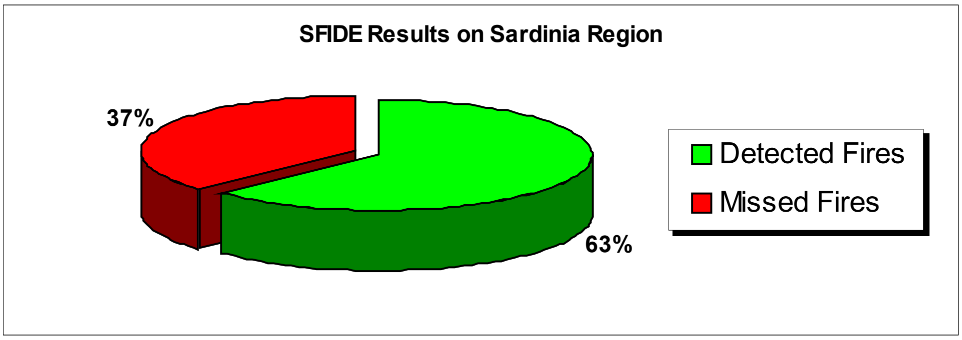

Figure 5. Percentage of detected and missed fires on the Sardinia island during the August 2006.

In few circumstances (2%) the SEVIRI data were unavailable during the event and other few cases the fires refer to areas of hot spot due to industrial plants. In most of the cases (53%) the sky was clear and the missed detection can be ascribed to the utilization of a too conservative threshold for false alarms minimization purposes. In fact, if we analyse the type of vegetation interest by the fire in the missed cases we can observe (Fig. 7) that in the 82% of the cases the burned area is a not forested area (grassland) for which a lower burning temperature can be foreseen. In conclusions, taking into account the percentage of missed fires, the percentage of the missed fire under clear-sky conditions and the percentage of undetected forest fires it results that the SFIDE algorithm has missed less than the 4% of the forest fires. This result is very important since it suggests that an improvement of the sensitivity of the algorithm can be obtained, in order to allows the detection of fires characterized by a low burning temperature, by assigning the thresholds on the base of the thermal history of each pixel.

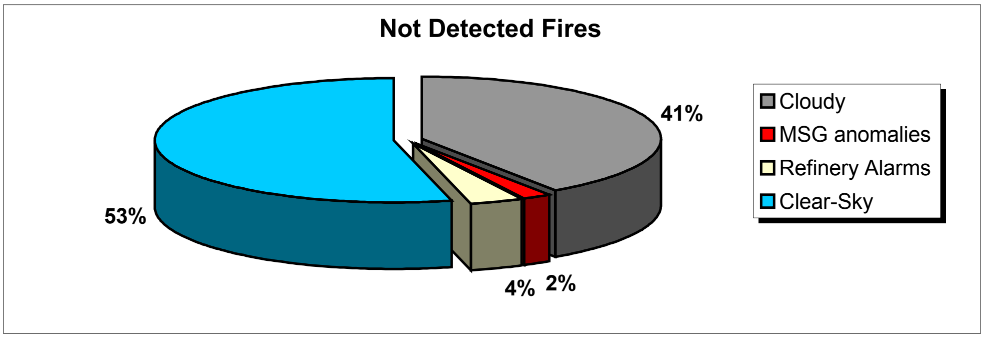

Figure 6 - Distribution of the undetected fires as function of the reason for missing.

Let us now to answer the question if the prompt detection allowed by the high temporal frequency of the SEVIRI images can improve the speedy of the contrast action. Fig. 8, showing the averaged differences $\Delta t = t_{sat}-t_{guard}$, gives an idea of this. The day-time has been divided in three 8-hours intervals. During the night, on average, the satellite based detection time results anticipated of about 11 min. with respect the ground-based observation. During the morning, afternoon and evening the alarms delivered by field guards result anticipated, in average, of 9-11 min. If we consider that the region we are considering for the comparison is one of the mainly affected by the summer fires problem, for which an extended network of ground observation turrets is used we can appreciate the potentiality of the a detection system based on SEVIRI images that can easily provide the same information for any other region in Italy.

Of course the CFS report cannot be used to estimate the sensitivity of the algorithm in terms of minima sizes of the detected forest fire since the sizes there indicated refer to the extent of the burned area at the end of the burning phase.

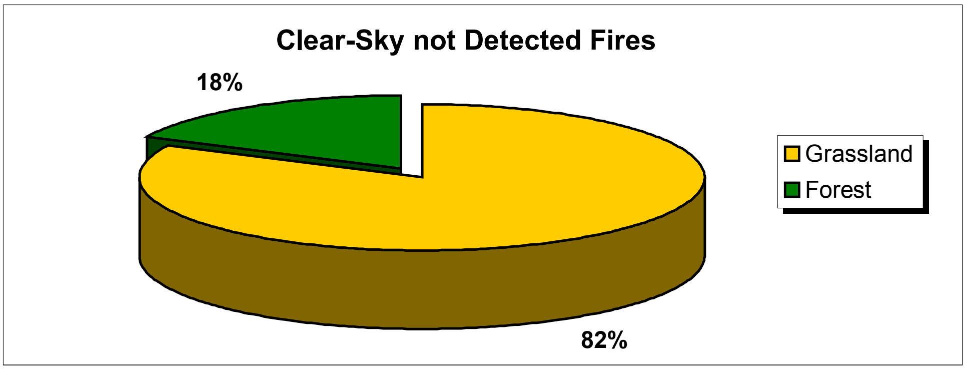

Figure 7 - Distribution of the undetected fires as function of the vegetation type.

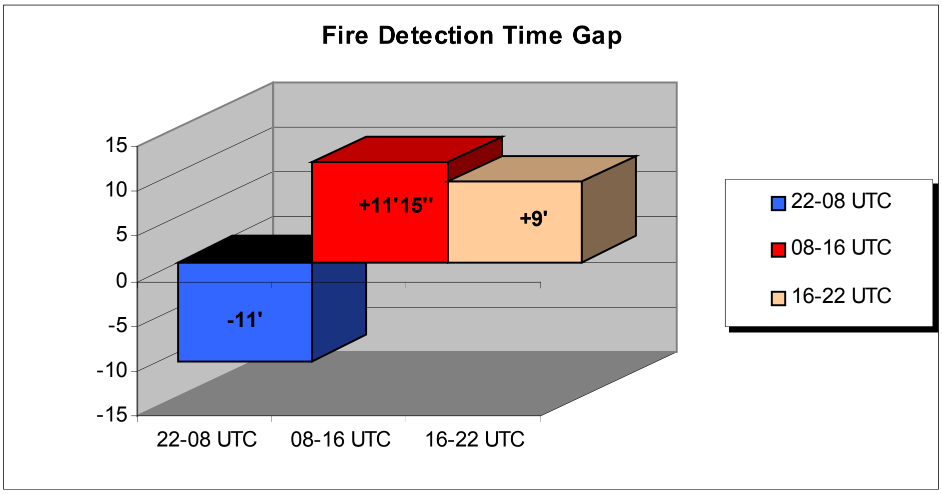

Figure 8 - Averaged differences in the detection time (t_{sat}-t_{guard}) for August. 2006

The high temporal frequency of the SEVIRI imagery allows following the fire evolution, providing a means to evaluate the efficacy of the fire fighting activities. An example is shown in figure 9. This case refers to the worst fire (1000 ha burned), which took place in Sardinia during the month of August 2006. From the figure (right) the behaviour of the fire can be easily monitored and the time when contrasting actions start to obtain some success can be observed (sudden brightness temperature decrease). As a consequence, we have an objective way, to follow the extinguishment process. In principle, the high image acquisition frequency can provide detailed information on the amount of biomass combusted (Roberts and others, 2005). To obtain this result the fire radiative power (FRP) must be derived from sub-pixel fires. Figure 9 (left) shows the fire radiative energy (FRE) emitted during the big fire above recalled from which the total amount of burned biomass can be estimated. The SFIDE algorithm, thank to its sensitivity, allows to detect small

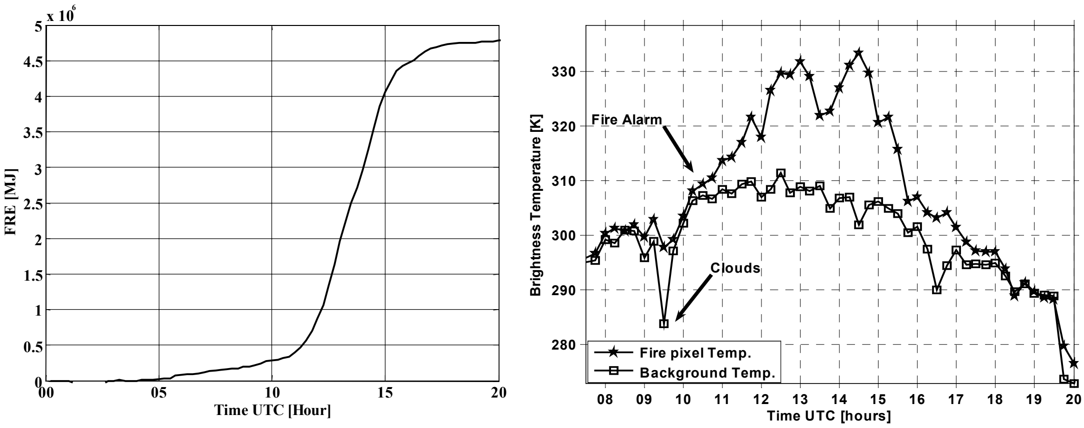

Figure 9 – Emitted fire radiative energy (FRE) and pixel brightness temperature (right) during the burning event.

fires characterized by FRP of the order of few MW (Fig. 10), this can improve the accuracy of the burned fuel biomass and pollutant emissions estimate .

Conclusions

This paper aims at assessing the performances of the CRPSM developed fire detection algorithm called SFIDE. This algorithm has been designed to exploit the MSG/SEVIRI high temporal image acquisition frequency for allowing a real time monitoring and detection of woodland fires.

The performances assessment has been carried out by comparing SEVIRI and MODIS satellite images for evaluating the accuracy in the fire geolocation, and in the estimate of the parameters like fire sizes and burning temperature. Further, to assess the detection sensitivity and promptness of the detection the SFIDE results have been compared with the information provided by Italian CFS (Corpo Forestale dello Stato) for the Sardinia region for a period spanning the month of August 2006. The comparison with MODIS based data shows that the geolocation accuracy is of about

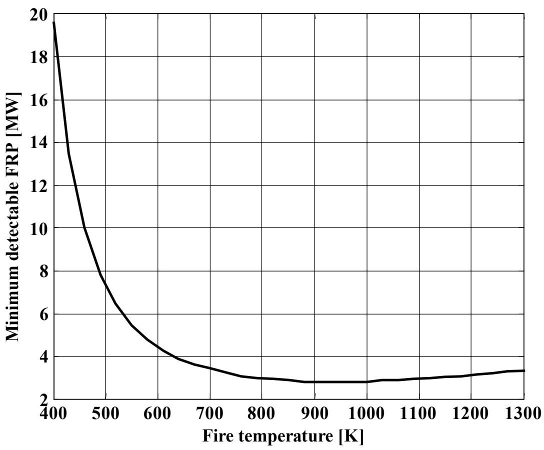

Figure 10 – Minimum fire radiative power (FRP) detectable using SFIDE algorithm.

1 km. This is compatible with the SEVIRI pixel size. Regarding the temperature and size of the fire it results that both parameters are generally overestimated by SEVIRI of less than the 20%.

The comparison with field data shows that less than the 4 percent of the forest fires, causing more than 2 ha of burned area, result missed by the SFIDE algorithm. The number of missed fires interesting not-forested areas results higher but this is mostly due to the excessively conservative value used for the detection threshold in the algorithm. From the point of view of the promptness of the detection the interesting result has been obtained that notwithstanding (as consequence of its state of region greatly affected by fires) the Sardinia region is provided of an extended network of fire guards during the night the satellite detection results in average anticipated of more than 11 min with respect to the ground based detection and during the day it results delayed of about 10 min.

The interesting performances of the detection algorithm are mostly a consequence of the application of a *change detection* technique that exploits the very high temporal resolution of the SEVIRI sensor. In fact, as demonstrated through the comparison with the MODIS based results, carried out during August 2006, this technique allows the detection of hot spots of extremely reduced sizes, if compared with the sensor pixel sizes (more than 15 km^2). The detectable fires can be 15000 times smaller than the spatial resolution of the instrument. The size of the fires detectable by applying the SFIDE algorithm to the SEVIRI images results suitable to meet the requirements posed by Italian Agencies, in charge for wild fires management, to establish a satellite based early fire detection system. Further the high sensitivity of the algorithm to small fires allows reducing significantly the minimum FRP and then the burned biomass and the pollutant emissions detectable.

Acknowledgement

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