SIGRI

SEVIRI/MSG sensor early fire detection performances assessment

G. Laneve, E. Cadau

CRPSM – Università di Roma "La Sapienza"

e-mail: laneve@psm.uniroma1.it

SIGRI

SUMMARY – 1

➢Forest fires represent the main cause of forest degradation in Italy and in the Mediterranean area countries (Spain, Portugal, Greece, France).

➢Forest fires have a direct economic impact related to the burned wood, the activities of prevention, fire-fighting and recover of burned areas. An economic impact of forest loss as part of the eco-system (reduction of the hydro-geological defenses, spoiling of tourist and landscape attractions, etc.).

➢To manage this problem an observation system able to provide a prompt detection and monitoring of fires and a synoptic view of the area of interest is required.

➢ Satellites seem to be the ideal instrument for this purpose, but the temporal frequency of the LEO instruments is generally a problem. The possibility of setting up an early fire detection system using the sensor SEVIRI on board of the geostationary satellite MSG has been demonstrated.

SUMMARY – 2

- The present paper aims to present the results obtained applying our 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.

- To assess the performances of the system its results have been compared with those obtainable from higher resolution sun-synchronous sensor data (MODIS and ASTER).

This activity is part of a program SIGRI (Integrated System for Fire Risk Management), funded by ASI, aiming to develop a system based on satellite data, able to provide information to the Institutions involved in the fire fighting activities, like: Forecast, Monitoring/Detection, Control/Fight/Propagation forecast, Evaluation of the burned area/Recover.

SIGRI

INTRODUCTION – 1

In previous papers we introduced a technique to detect small fires based on exploiting the high temporal frequency guaranteed by SEVIRI sensor on board of MSG and we tried to assess the detection limits reachable with our algorithm by comparing the SEVIRI fire products with those provided by an higher spatial resolution sensor like MODIS.

The idea to use geostationary satellite to monitor wild fires is not new since a great experience has been gained in the past, on the American continent, (ABBA algorithm, developed for the GOES/VAS radiometer).

INTRODUCTION – 2

The innovation represented by the application described herein consists in the attempt to exploit the quasi-continuous Earth observation that SEVIRI provides to set up an automatic wildfire early detection system. The motivations of such a system are:

⇒ a prompt detection can help in reducing the response time to the event;

⇒ in presence of several simultaneous fires, a prompt detection can provide, the decision makers with an objective element useful to optimise limited resources. This will help to set the interventions priorities, on the base of the dynamics and size of each detected fire.

The detection algorithm, applied to SEVIRI images, able to reveal, at Italian latitudes, fires covering an area of the order of 0.1 ha, is specially designed to exploit the high temporal frequency of the images acquisition. Thus, such an algorithm, even if based on MIR and TIR bands, as for 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.

SIGRI

INTRODUCTION – 3

This paper aims to show the performances of the algorithm developed at CRPSM and presented in previous papers* by comparing its results with these provided by MODIS for a period covering the month of August 2006.

Several studies have assessed the capability of suitable algorithms to detect fires of very small size, compared with the satellite image pixel size, using MIR and TIR spectral channels.

The limited temporal revisit frequency of 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, notwithstanding its low spatial resolution, it is interesting to explore the actual applicability of the MSG satellite.

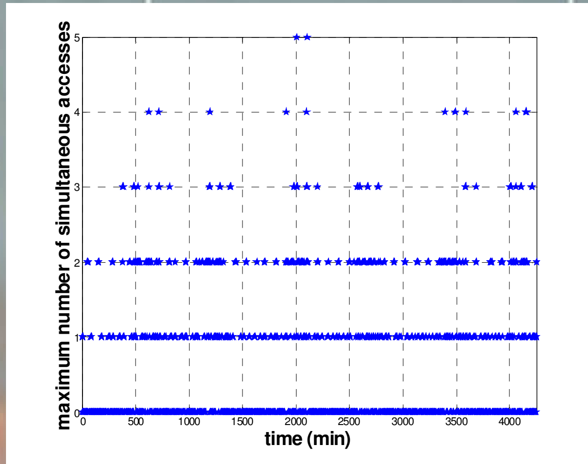
(The proposed algorithm has been described in a paper published on TGRS, October 2006).

Earth Observing Satellite spurious constellation

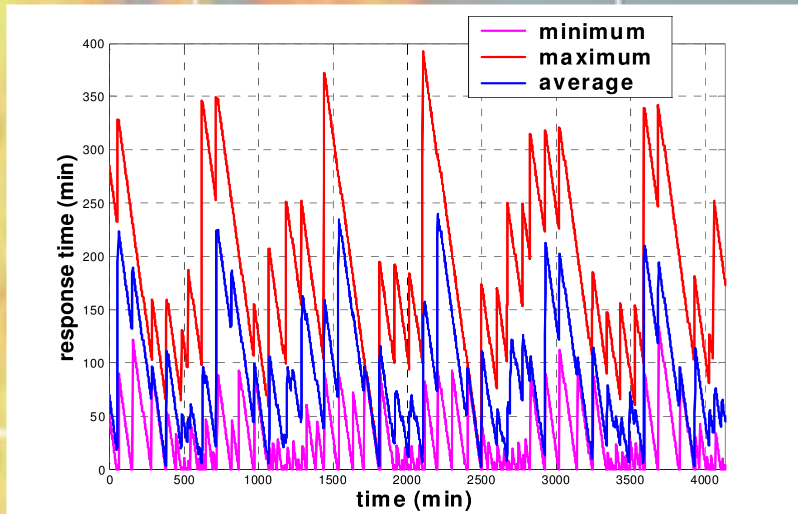
SIGRI

Available satellite considered

Satellite	Sensor	Resolution/Swath
ADEOS II	GLI	1 km / 1600 km
AQUA	MODIS	250 – 1 km / 2330 km
EO-1	LAC	30 m / 185 km
ERS-2	AATSR	1 km / 500 km
ENVISAT	MERIS	300 m or 1.2 km 575 km or 1150 km
Feng Yun 1C	VIRR	1.1 km / 2700 km
IRS-P3	WIFS	188 m / 770 km
LANDSAT 5	TM	30 m / 185 km
LANDSAT 7	ETM+	30 m / 185 km
NOAA 12	AVHRR	1.1 km / 2700 km
NOAA 14	AVHRR	1.1 km / 2700 km
NOAA 15	AVHRR	1.1 km / 2700 km
NOAA 16	AVHRR	1.1 km / 2700 km
NOAA 17	AVHRR	1.1 km / 2700 km
OCEANSAT	OCM	360 m / 1440 km
RESURS	MSU-SK	170 m / 710 km
SAC-C	MMRS	175 m / 360 km
SeaStar	SeaWiFS	1.1 km / 2800 km
SPOT 4	VMI	1.1 km / 2350 km
SPOT 5	VMI	1.1 km / 2350 km
TERRA	MODIS	250 - 1 km / 2330 km



Maximum number of accesses over a given location within the considered region for the spurious constellation composed by the 21 satellites.



Response time for the spurious constellation composed by 21 orbiting satellites. Response time is defined as the time needed by the constellation to observe a considered location starting from a given instant of time.

INTRODUCTION – 5

Present status of satellite based fire detection systems:

Southern Europe is monitored (SAI/JRC World Fire Web Initiative) using daily data from NOAA/AVHRR and an algorithm proposed by Flasse and Ceccato. The European Space Agency (ESA) uses the night-time images of the sensor ATSR-2 (Along Track Scanning Radiometer) on board of ERS satellite.

On the American continent, GOES has demonstrated the utility of meteorological geostationary satellite in monitoring forest fires. The ABBA (Automated Biomass Burning Algorithm) algorithm, is based essentially on the estimate of the brightness temperature in the usual two channels at 4 μm and 11 μm. The minimum size of a fire detectable by this algorithm, if its burning temperature is around 880 K, goes from 0.5 ha at equator to about 2 ha at 50° of latitude.

Based on the images of the sensor MODIS on board of TERRA and AQUA satellites a Rapid Response System has been developed by NASA to provide rapid access to MODIS data globally, with emphasis on active fire data.

AFIS (Advanced Fire Information Service) is a near real time operational satellite fire monitoring system. It aims to provide information regarding the prediction, detection and assessment of fires, using Remote Sensing and GIS technology, could cause flashovers on the power transmission lines of South Africa.

DATA and METHOD- 1

The SEVIRI 15 min. temporal resolution data used in the analysis have been directly acquired at CRPSM in Rome.

MODIS and ASTER images have been downloaded by NASA website.

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 algorithms, has been applied. This algorithm (called SFIDE, System for Fire Detection) uses 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.

DATA and METHOD - 2

Fig. 1, as function of the average temperature of the fired pixel, for different background conditions, shows the minimum sizes of the fire theoretically detectable, using the SFIDE (System for Fire Detection) algorithm. Theoretically means that these minima sizes are 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 the results obtained by comparing SEVIRI based fires detection techniques with MODIS and ASTER based are reported.

The comparison covers a period of a month, corresponding to August 2006. It allows to evaluate the performances by the SEVIRI system, when a fire detection algorithm, based on a change detection method, is adopted.

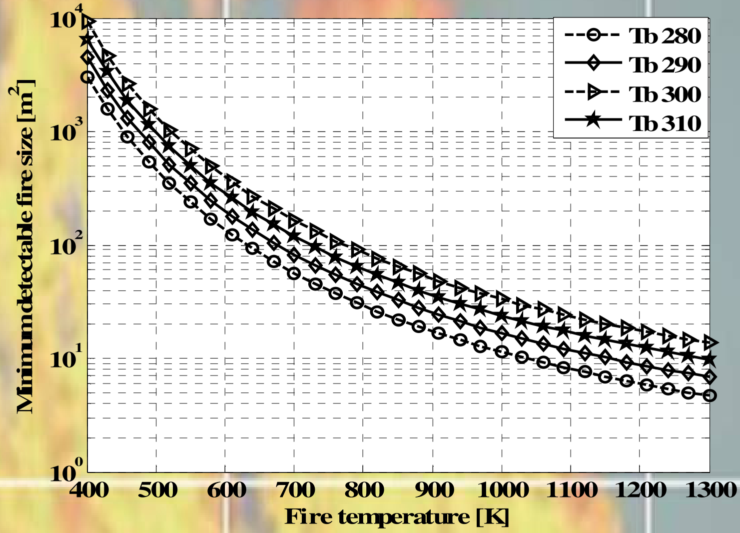


Figure 1. Minimum size of a fire theoretically detectable by applying the SFIDE algorithm to SEVIRI images. A NEΔT = 0.2 K has been assumed for the channel 4.

SIGRI

RESULTS - 1

The results provided by the algorithm SFIDE, applied to SEVIRI images, are compared with those obtained by the Rapid Response System (RRS) based on the MODIS images.
Fig. 2 shows the distribution of fires, for the period of 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 shows the fires detected by both approaches and the blue dots these detected only by SFIDE.

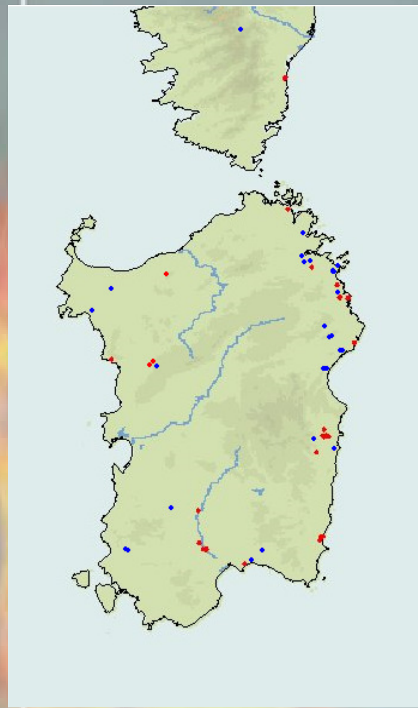


Figure 2. Distribution of fires, as detected by both RRS using MODIS and SFIDE using MSG (red spots) and by SFIDE only (bleu spots) for the month of August 2006 on the Sardinia island.

RESULTS – 2

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 those provided by RRS. 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. All the fires detected by MODIS have been detected also by the MSG-SFIDE algorithm, this performance requires the introduction of limited uncertainty values (thresholds) since one of these fires, detected on the 22nd of August at 12:05 UT, results smaller than 0.05 ha in size.

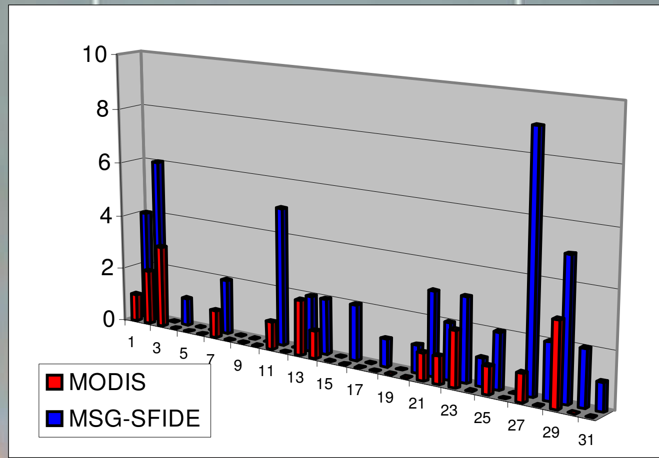
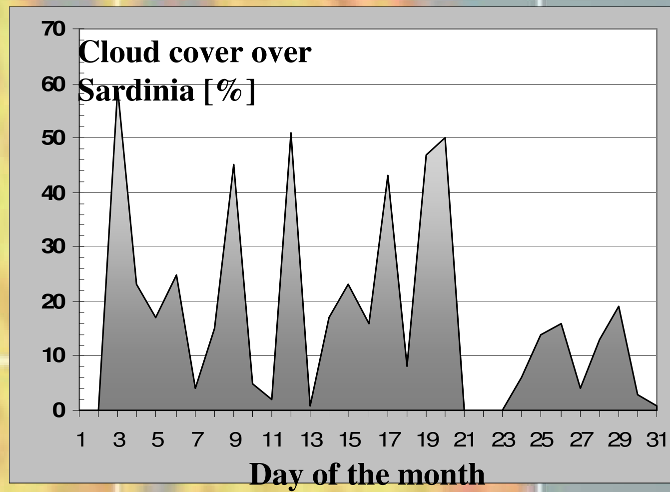


Figure 3. Distribution, day by day, of the fires, as detected by RRS using MODIS and SFIDE using MSG for the month of August 2005 on the Sardinia region.



RESULTS – 3

The comparison between the positions of the fires detected by using MODIS and SEVIRI images allows to evaluate the accuracy in the geo-location of the MSG based fires. Fig. 5 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 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 perfectly 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. The results of this approach will be the subject of a next paper.

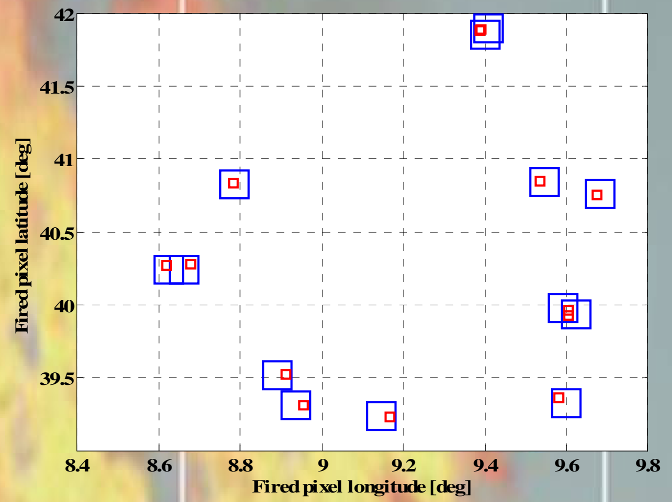
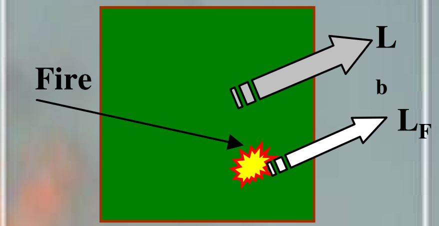


Fig. 5. Geographic distribution of the fires detected during the month of August 2006 by using RSS (on MODIS) and SFIDE (on SEVIRI).

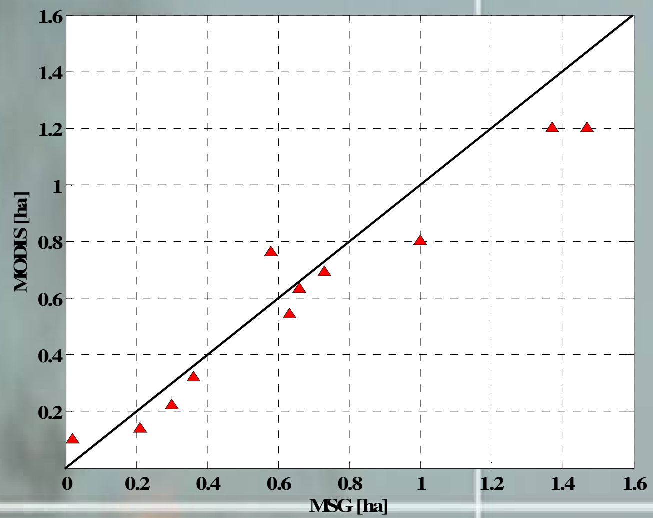
RESULTS – 4

SIGRI

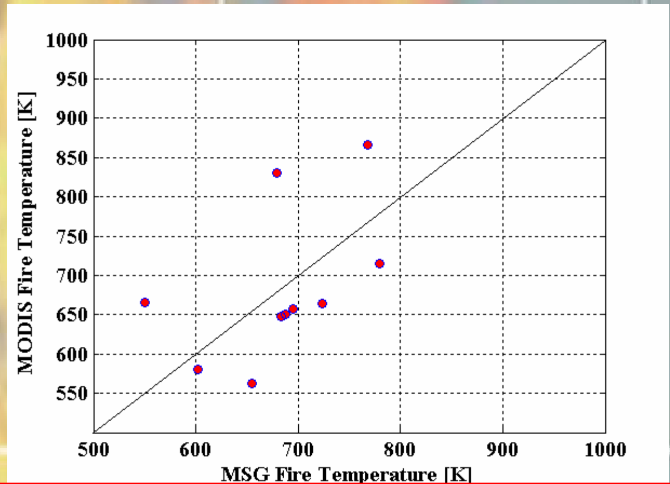
With reference to the fire sizes and temperature, estimate by using the classical Dozier approach, we can say that SEVIRI, as possibly expected, tends in general to overestimate dimensions and temperatures of a 20% or less, with respect to MODIS.



Schematic representation of a fire covering part of a satellite image pixel.



Comparison between the sizes of the fires detected during the month of August 2006 obtained applying the Dozier relationship.



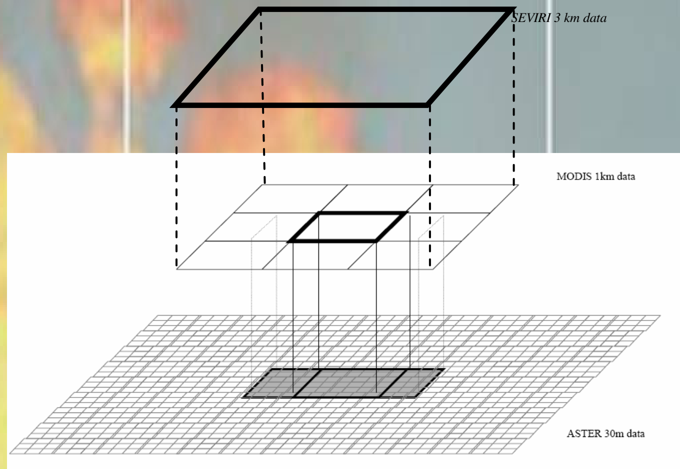
Comparison between the temperature of the fires detected during the month of August 2006 obtained applying the Dozier relationship.

SIGRI

RESULTS – 5

A particular event, happened in the Calabria region on the 21st of August 2006, has been deeply analyzed by using a coincidence of SEVIRI, MODIS and ASTER images. The simultaneous acquisition has been obtained at 9:45 UTC allowing the analysis of the event with sensors at difference spatial resolution.

This circumstance can be exploited: to analyze better the errors in the estimation of fire size and burning temperature, that represent two products of the SFIDE algorithm. Using ASTER we can also approximately estimate the burning temperature of the fire, using the VNIR, not saturated, channels.



Comparison of the pixel sizes for the three sensors used in the comparative analysis.

RESULTS – 6

SIGRI

With reference to the day 21st of August 2006, fig. 6 shows the hot spots provided as product by the RRS system.

MSG	***Pixel 1***		***Pixel 2***		
	R	***T***	***R***	***T***	***Time***
•Ch4	1.28 1.37 1.54	306.7 308.4 311.4	1.28 1.42 1.66	306.7 309.2 313.5	9:00 9:15 9:30
Ch9	125.1 125.9 125.5	307.5 307.9 307.7	125.1 125.5 125.1	307.5 307.7 307.5	9:00 9:15 9:30
•Size	0.3 ha		0.3 ha		9:30
•Temp	640 K		670 K		

•MODIS	***Pixel 1***	***Pixel 2***	***Time***
•ΔT [K]	6.25	6.67	
T^b_{31} *[K]*	308.86	308.93	
T^b_{21}*[K]*	315.10	315.60	
T^f_{31}*[K]*	309	310.17	
T^f_{21}*[K]*	332.70	331.60	
•TRP *[MW]*	23.02	20.79	
Estimate size	0.21 ha	0.18 ha	9:45
Temp.	665 [K]	665 [K]	

Tab. 1 provides the characteristics of one of these fires, the one highlighted with the red square, as computed by using MODIS and SEVIRI images. The good agreement of the results can be appreciate (size about 0.5 ha, T_f near 650 K). Now let as estimate these quantities using the ASTER image. The channels 9 (2.39 µm), 10 (8.29 µm), 13 (10.66 µm) and 14 (11.32 µm) are considered, since they are the more suitable to analyze thermal anomalies.

TAB. 1 Estimate characteristics of one of fire detected simultaneously on the SEVIRI and MODIS images.

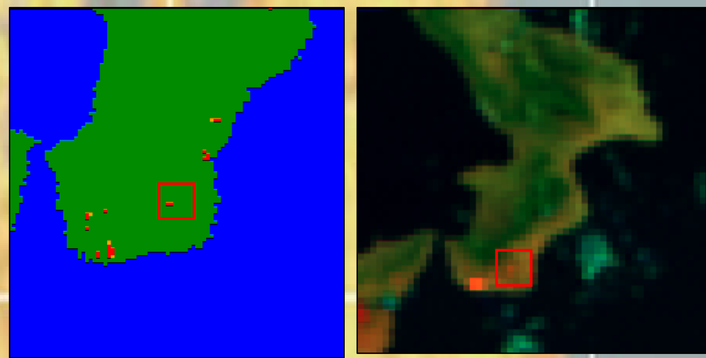


Fig. 6 Fires detected on the 12:05 UTC MODIS image of the 21st of August 2006. The figure on the left shows the RRS product. On the right is a SEVIRI false colour image (R=4, G=2, B=1).

RESULTS – 7

SIGRI

Fig. 7 shows a RGB combination (Fig. 7, left) of the channels 5 (2.17 μm), 4 (1.66 μm) and 1 (0.56 μm), respectively. In the same figure, a grey scale image of the channel 9, where mostly of the fired pixels result saturated, is reported together with a TIR (channel 13) image of the same fire. In particular, according to Fig. 8, the ASTER channel 9 can be saturated by a fire, due to the small pixel size and the spectral position of the band, lower than 100 m^2, even if its burning temperature is lower than 600 K (*smoldering* phase). In channel 10 the saturation is reached, at the same temperature for a fire size larger than 1000 m^2

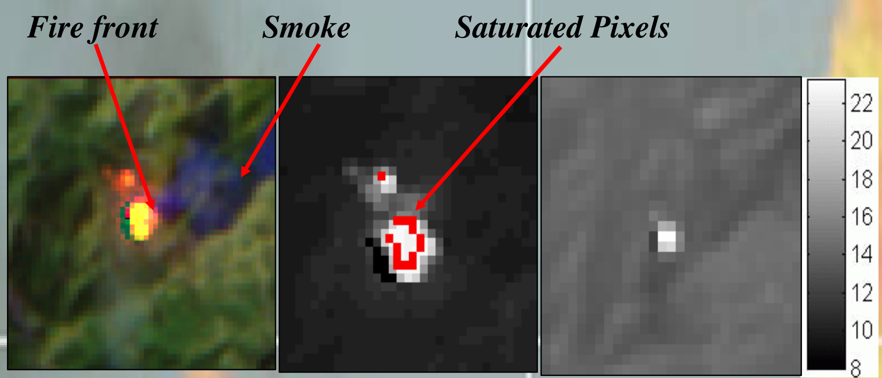


Figure 7. ASTER image of one of the fires detected the 21st of August 2006. RGB image of the channels 5, 4, 1 (left), MIR image (middle), TIR image of the fire (right).

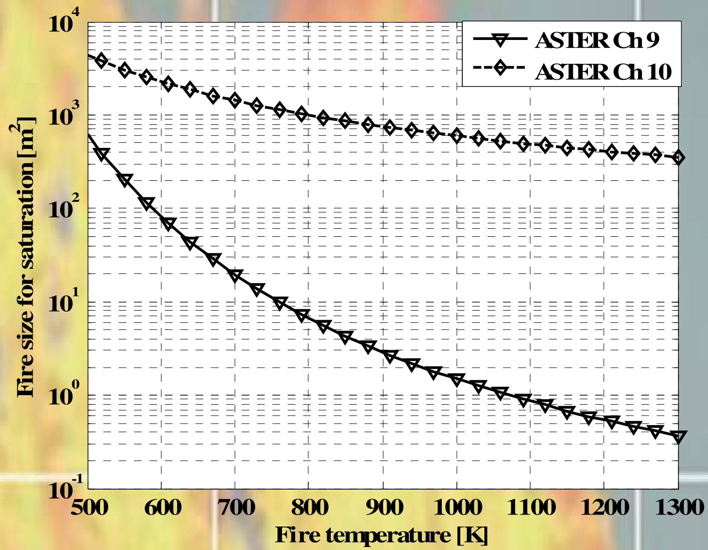


Figure 8. Saturation condition of the ASTER sensor channel 9 and 10. The minimum fire size capable to saturate the channel is given as function of the burning temperature.

RESULTS – 8

SIGRI

When the radiance from the fired pixel reaches the saturation level of the channel the Dozier relationship cannot be applied. Of course, the number of saturated pixel, depends both from the spatial resolution and the particular spectral channel considered. In fact, as Tab. 2 shows the extension of the fire under consideration is able to saturated 14 pixel (of channel 9) while 1 pixel results saturated at channel 10, and 2 (at channel 13). The saturation condition is never reached in the channel 14. Then, we cannot use the band 9 to estimate the fire size. In fact, we use the channel 10 and 14 to evaluate the fire temperature and size in one of the pixel that results not saturated in these two channels.

Further we can deduce the size and temperature of the fire interesting the other pixel, where only the channel 14 results not saturated, observing that in that pixel no flames are visible by the VNIR channels then its temperature can be considered to be around 600 K or lower. Furthermore the extension cannot be higher than 2000 m^2 otherwise also the channel 14 becomes saturated.

TAB. 2 Number of saturated pixels, at the different spectral channel of ASTER, for the fire under study.

ASTER	*Pixel Sat.*	*Resolution [m]*	*Size [m^2]*	*W/(m^{2}sr µm) Max. rad*
Band 09	14	30	12600	8.08
Band 10	1	90	8100	28.17
Band 13	2	90	16200	23.31
Band 14	0	90	0	21.33

RESULTS – 9

SIGRI

Following this argument we find:

1. a size of 3100 m^2 at a temperature of 510 K applying Dozier at channels 10 and 14 on the not saturated pixel;

2. a size of about 2000 m^2 with a temperature of the order of 600 K on the other one, where only the channel 14 results not saturated.

In conclusion, we have a total dimension of the fire of 0.5 ha with an averaged temperature comprised between 500 to 600 K.
Even if this kind of analysis must be extended to other cases for being considered exhaustive it is sufficient to give an idea of the potentiality of the SEVIRI images for hot spots detection.
The channel 9 image having 30 m spatial resolution confirms this result.
In fact, considering the number of saturated pixels (Tab. 2), the fire temperature estimated above and the plots in Fig. 8 we can estimate a fire size of the order of 5000 m^2.

RESULTS – 10

Since the VNIR spectral channel of ASTER, can be considered enough small (res. 15 m) to be fully covered by the flaming part of a fire we can exploit it to estimate the flame temperature of one of the fire present on the scene of 21st of August. Let us consider the radiances measured by the ch. 3 (0.807 µm). The contribution due to the sun, *Lb*, can be approximately estimate comparing the signal from two almost adjacent pixels: one interested by flames and the other fire free. We assume that they have the same reflectance, an hypothesis acceptable given the size of the pixels. The difference between radiances: L_F = *Ltot - Lb* provides an approximate estimate of the radiance due to the fire, L_F, of the order of 50 $W/m^2sr^{-1}\mu m^{-1}$. By inverting the Planck equation a temp. higher than 1000 K can be found. This value is compatible with the typical temperature of a fire in *flaming* phase. A similar temp. can be computed by considering the ASTER ch. 2 (0.661µm).

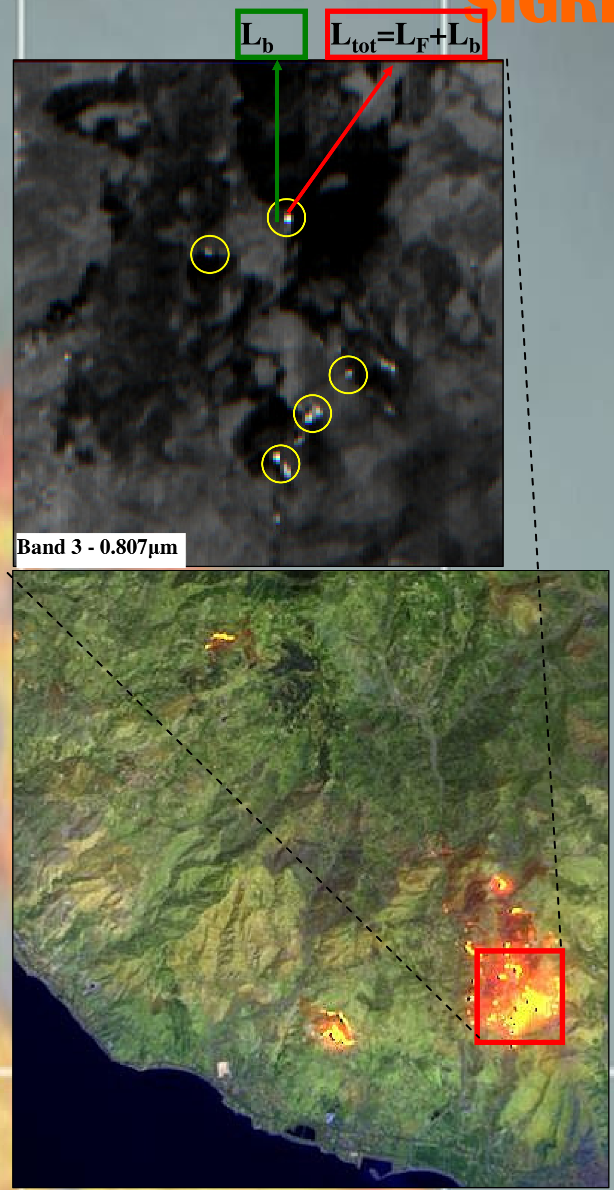


Fig. 9. RGB combination of channels 5, 4 and 1 of the ASTER image.

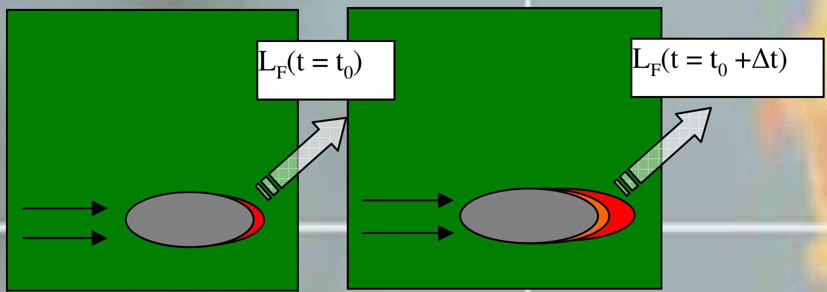
RESULTS – 11

SIGRI

The high frequency in the image updating guaranteed by SEVIRI allows to monitor the fire evolution with the time. In fact, if the size of the area interested by the fire, defined as burning area at the observation time, and its temperature can be determined, the global intensity of the fire can be monitored by using the definition of FRP (Fire Radiative Power, portion of chemical power emitted by the vegetation during combustion):

$$FRP = \varepsilon \cdot \sigma \cdot A_f \cdot T_f^4$$

As consequence the biomass burning can be estimate and the burning rate can be assessed comparing the variation with the time of the fire sizes.



Schematic representation of the time fire evolution.

Specie legnosa	Potere calorifico superiore assoluto teorico kcal/kg	Peso specifico kg/mc	Potere calorico inferiore assoluto effettivo kcal/kg	Potere calorifico inferiore specifico kcal/mc
ABETE BIANCO	4.650	440	3.720	2.046.000
ABETE ROSSO	4.857	450	3.886	2.185.650
ACERO	4.607	740	3.686	3.409.180
BETULLA	4.968	650	3.974	3.229.200
CARPINO NERO	4.640	820	3.712	3.804.800
CASTAGNO	4.599	580	3.679	2.667.420
CERRO	4.648	900	3.718	4.183.200
CIPRESSO	5.920	620	4.736	3.670.400
FAGGIO	4.617	750	3.694	3.462.750
FRASSINO	5.350	720	4.280	3.852.000
LECCIO	4.329	950	3.608	3.427.200
LARICE	4.050	660	3.240	2.673.000
ONTANO	4.400	540	3.520	2.376.000
ORNIELLO	4.059	760	3.382	2.570.000
PLATANO	3.539	690	2.949	2.034.900
PIOPPO CIPRESSINO	4.130	500	3.304	2.065.000
ROBINIA	4.500	790	3.600	3.555.000
ROVERELLA	4.631	880	3.705	4.075.000

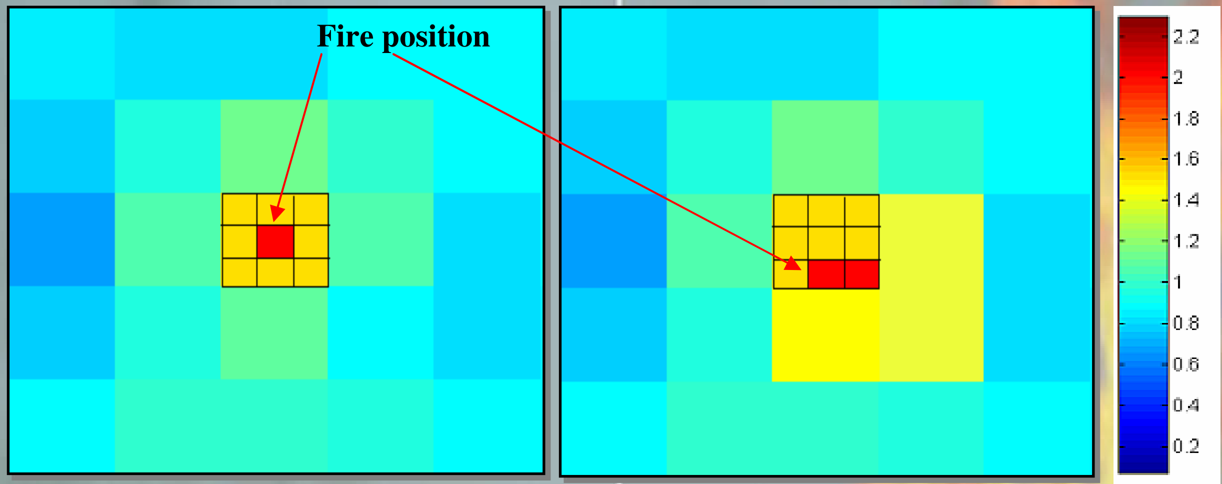
Energetic characteristics of the main died and health woods available in Italy.

SIGRI

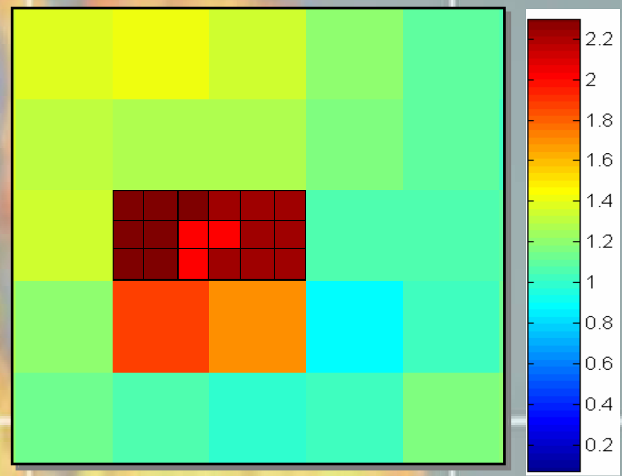
FUTURE STUDIES

• **Improve geo-location of the fire.**

The SEVIRI pixel can be divided in sub-pixels, and the distribution of temperature in the surrounding pixels can be used to locate the fire in one of these sub-pixels.



Example of possible positions of the fire in a pixel (Radiance in mWatt/m^2 sr).



Example of the possible fire position retrieved by radiance distribution on the SEVIRI pixels (radiances in mW/m^{2}sr.

CONCLUSIONS - 1

SIGRI

❖ This paper is focused on the analysis of the performances of an algorithm developed to allow real time monitoring and detection of woodland fires.

❖ The developed processing chain, based on SEVIRI images, allows the detection of fires as small as 1000 m^2. These performances have been validated using higher resolution sensors. In particular through a comparison with the MODIS based results on an interval period covering the month of August 2006.

❖ The comparison with MODIS and ASTER allowed also to verify the accuracy in the location of the fire and to assess the accuracy of the estimate of it size and temperature.

❖ Both fire sizes and temperatures estimated by using SEVIRI result overestimated, with respect the MODIS, result less than the 20 % and these quantities result quite accurate if compared with these obtainable by the ASTER sensor.

SIGRI

CONCLUSIONS - 2

❖ The size of the fires detectable by applying the change detection technique to the SEVIRI images <u>results suitable to meet the requirements</u> of the Italian Agencies, in charge for wild fires management, to establish a satellite based early fire detection system.

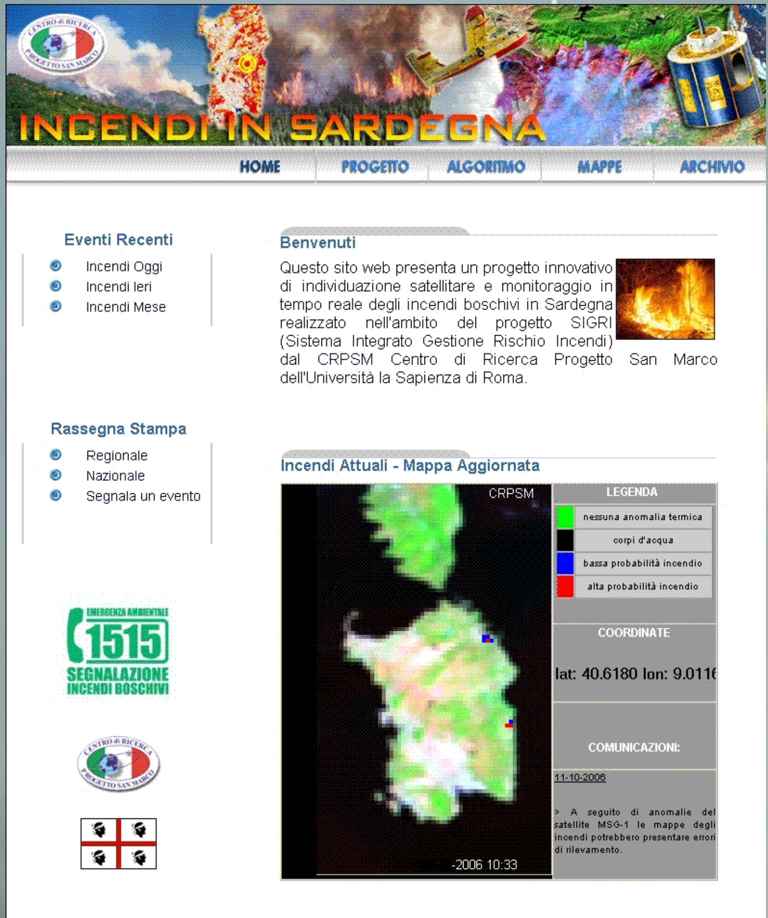
❖ Regarding the accuracy of the estimate of the fire characteristics, such as size and temperature, it is necessary to extend the validation campaign using also, if possible, ground-airplane-based observations during the events, and using other cases where ASTER images are available, acquired simultaneously with the geostationary satellite.

❖ Future activities regard:

- the improvement of the geo-location of the fire considering a sub-pixel approach,
- the estimate of burned biomass and rate of burning.

Thank you for your attention

Toward a real-time operational system



Emergenza incendi

Gallura in fiamme turisti in fuga

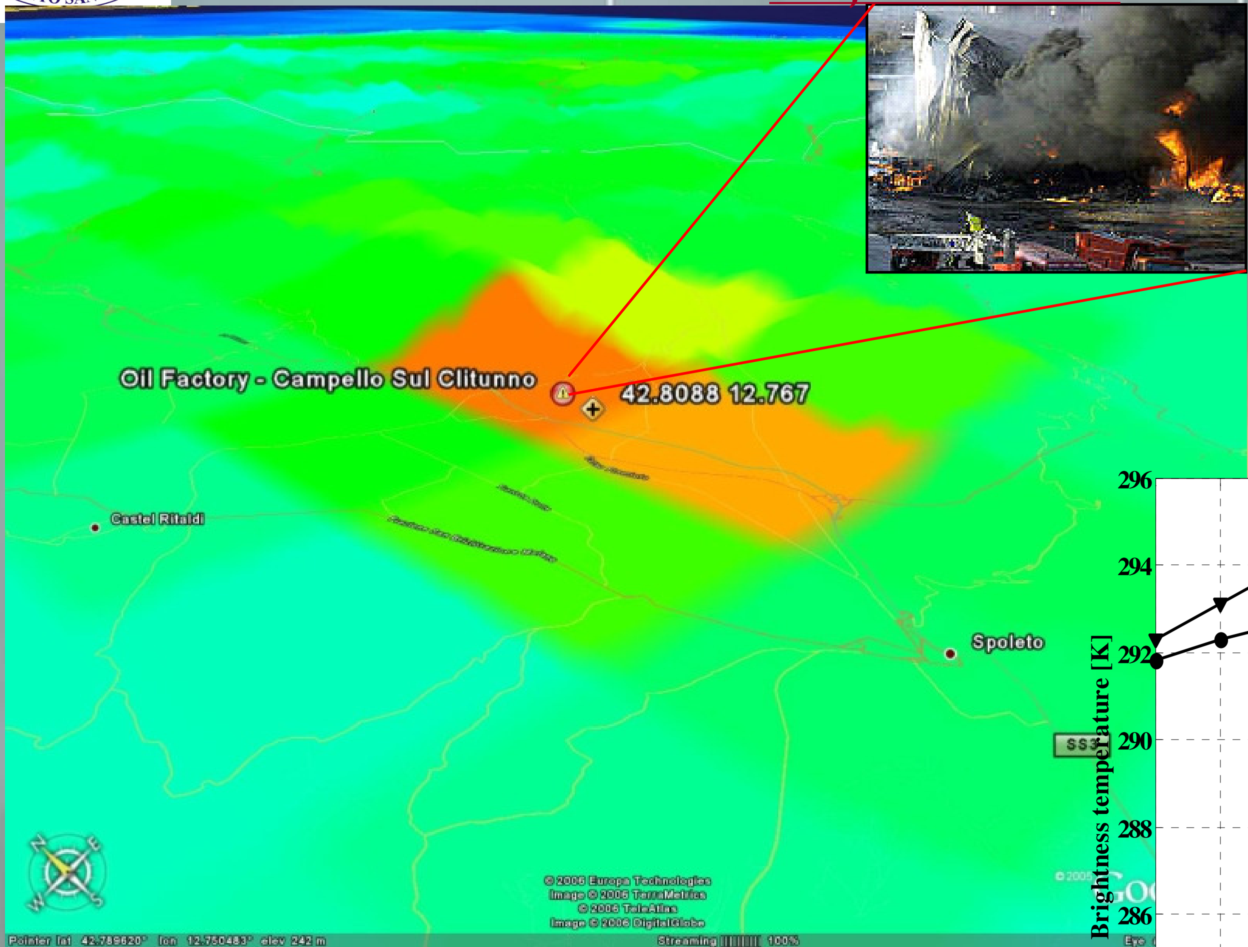
Roghi dolosi a Porto San Paolo e San Teodoro: evacuati abitanti e bagnanti. Ospedali presi d'assalto e quasi cento ettari distrutti dal fuoco. P. 32-33

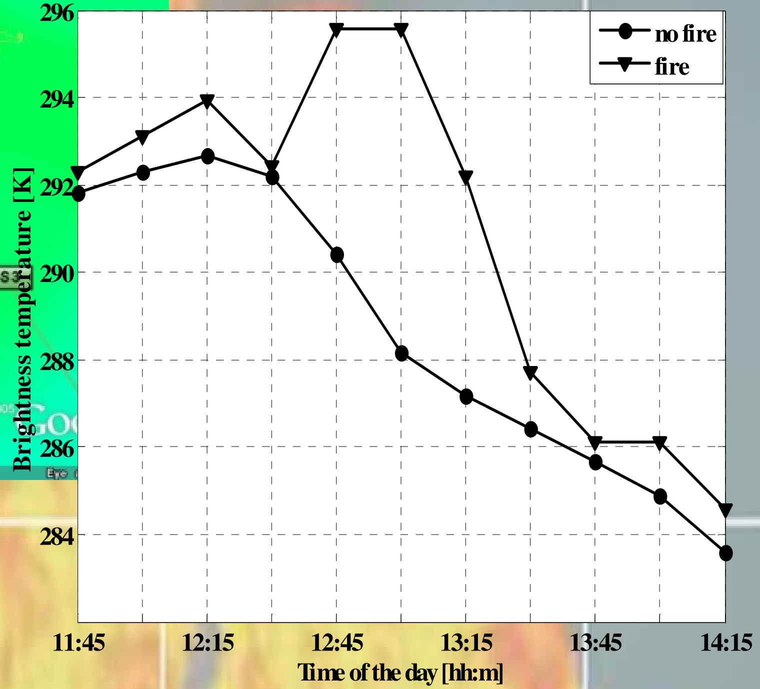
Real-time detection of wild fires in Sardinia, CRPSM web-site, www.psm.uniroma1.it

Toward a real-time operational system:

not just wild fires

SIGRI





25° of November 2006, oil factory explosion in Umbria-Italy, as detected by SFIDE algorithm applied to SEVIRI.