ROBUST SATELLITE TECHNIQUE (RST-FIRES) FOR TIMELY DETECTION OF FOREST FIRES BY GEOSTATIONARY SATELLITE DATA

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Abstract

Usefulness of satellite systems in monitoring fires has been being recognized for years, but satellite-based methods have been originally applied only to polar-orbiting sensor data like NOAA-AVHRR (*National Oceanic and Atmospheric Administration - Advanced Very High Resolution Radiometer*), ERS-(A)ATSR(-2) (*European Remote Sensing Satellite - (Advanced) Along Track Scanning Radiometer*), and more recently EOS-MODIS (*Earth Observing System - Moderate Resolution Imaging Spectroradiometer*). In this context, geostationary sensors, despite their coarser spatial resolution (3-4 km), have been recently taken into account thanks to their very high time repetition rate which may actually give more chance to detect short-lived fires, starting fires or fires with activity which has a strong diurnal cycle. This seems particularly important for European Countries (mainly in the southern part) which often suffer from short-lasting but noxious fires and/or events frequently occurring between 12:00 and 14:00 local time.

European Countries may benefit of MSG-SEVIRI (*Meteosat Second Generation – Spinning Enhanced Visible and Infrared Imager*) geostationary sensor offering a temporal resolution from 15 to 5 (in case of MSG Rapid Scanning System) minutes. SEVIRI-based fire products may give support to ground surveillance systems and help Civil Protection Services in timely detecting events for rapidly intervening before fire spreading as well as in monitoring ongoing events for optimizing ground and aerial resources.

In the last years, many algorithms of fire detection have been adapted to MSG-SEVIRI starting from other geostationary sensors (e.g. GOES - *Geostationary Operational Environmental Satellites*) or have been specifically designed for it. They are generally based on fixed thresholds (single/multiple channels or contextual methods) so that they are often a source of false alarms or show a low sensitivity in detecting small fires. Any case, their performances seem to be not adequate to civil protection requirements, mainly in Southern Europe.

In this work, results of RST-FIRES (Robust Satellite Techniques for Fire detection) implemented to MSG-SEVIRI data are shown. Validation of RST-FIRES performances have been evaluated by means of a Total Validation Approach (TVA), based on a systematic check of detected hot spots through a direct ground observation of dedicated light aircrafts or ground voluntary brigades. RST-FIRES performances are presented and discussed in comparison with other SEVIRI-based fire products: two Eumetsat products directly acquired at the EUMETCast station of University of Basilicata (FIR - *Active Fire Monitoring* - and FD&M - *Fire Detection and Monitoring*) as well as a product which is freely distributed on the web (SFIDE - *System for FIre Detection*).

INTRODUCTION

Wildfires represent a calamity for many Countries in the world due to their local and global consequences on climatic, atmospheric, and ecological processes. Satellite systems have always supported studies on atmospheric and climatological effects produced by fires, but they showed to be useful also in monitoring events themselves. In this context, the most used products have been traditionally based on polar-orbiting sensor data like NOAA-AVHRR, ERS-(A)ATSR(-2), and more recently EOS-MODIS, mainly thanks to their high spatial resolution and acquisition at a global scale. However, in the last decade, the positioning of several meteorological geostationary satellites along the equator plane, together with improved technical characteristics, led to a greater attention on this kind of sensors to be profitably used also in detection and monitoring of fires.

Geostationary satellite sensors, despite their coarser spatial resolution (3-4 km), seem actually able to monitor events better than polar ones thanks to their very high temporal resolution, provided that a suitable fire detection algorithms is used. High repetition time rate of geostationary orbiting sensors may give more chance to detect short-lived fires (often registered in Southern Europe), starting fires or fires with activity which has a strong diurnal cycle (for instance, the highest fire occurrence in Europe is between 12:00 and 14:00 local time). Therefore, areas like southern Europe may really benefit of geostationary rather than polar satellite-based systems and, in particular, may advantage of MSG-SEVIRI temporal repetition from 15 to 5 minutes (in the case of Rapid Scanning Service). The timely detection of fires can help Forest Fire and Civil Protection Services to better manage wildfires: minimizing the response time to the event, it is possible to face it when it is still under control. In addition, in the presence of several contemporarily events, promptly detection and quasi-continuous monitoring can provide useful information to decision makers for optimizing ground and aerial resources.

In the last years, many algorithms of fire detection have been adapted to SEVIRI data from other geostationary sensors (e.g. Prins et al., 1992) or have been specifically designed for it (e.g. Eumetsat, 2007, 2010; EUMETSAT LSA SAF, 2009; Amraoui et al., 2010; Laneve et al., 2006; Roberts and Wooster, 2008; Costantini et al., 2006; van den Bergh et al., 2009; Calle et al., 2006). Many of them are fixed thresholds (single/multiple channels or contextual) methods and, as already shown for algorithms applied to polar orbiting sensors (e.g. Kaufmann et al., 1990; Flasse and Ceccato, 1996), such a kind of methods is often a source of false alarms (explicative cases are described in San-Miguel-Ayanz et al., 2005 and Marchese et al., 2010). In order to minimize such false alarms, thresholds are often chosen to be very selective and only large events are detected. This translates into a low sensitivity which is not adequate to civil protection requirements in Southern Europe. Moreover, validation of such algorithms is generally performed considering official databases or, more frequently, a sensor-to-sensor comparison. In both cases the actual performances of the algorithm cannot be completely evaluated because nothing can be certainly said about detected thermal anomalies when no corresponding event is recorded on official databases or no passes of the comparing satellite are available. Differently from sensor-to-sensor comparison, validation by means of event official registers gives the opportunity of verifying anomalies during all the day, but thermal anomalies with no corresponding listed events are generally flagged as “false alarms”.

The multi-temporal change-detection technique for fire detection, RST-FIRES, described in the following, was indeed tested during a series of Total Validation (e.g., Mazzeo et al., 2009; Filizzola et al., 2010) campaigns, carried out in close collaboration with Civil Protection and local authorities of Lombardy, Basilicata and Sicily regions. Dedicated light aircraft surveys and voluntary brigades available for direct ground observations made a systematic check of RST-FIRES hot spots. They resulted to be related to actual fires (large fires, burning stubbles or very small fires) as well as to other, actually existing, hot sources like chimney of industrial plants with variable thermal emission regimes. Although RST-FIRES have been applied both to polar (Baldassarre et al., 2009; Marchese et al., 2010; Mazzeo et al., 2007, 2009) and geostationary satellite data, in this work only performances of RST-FIRES applied to MSG-SEVIRI are presented.

Finally, a comparison among RST-FIRES and Eumetsat products (FIR and FD&M), directly acquired at the EUMETCast station of University of Basilicata, as well as a product freely distributed by means of a plug-in (SFIDE) is also presented and discussed.

RST-FIRES

The RST-FIRES algorithm is based on the general scheme called RST (Robust Satellite Techniques) which is described in detail in Tramutoli (1998, 2007). The RST approach only uses multi-temporal co-located satellite records to characterize satellite signal in terms of its expected value and natural variability for each pixel of the satellite image to be processed. On the basis of such a preliminary signal characterization, “anomalous” signal patterns may be identified by using a local change detection index, named ***ALICE*** (*Absolutely Llocal Index of Change of Environment*):

$$\otimes_V(x,y,t) = \frac{[V(x,y,t) - \mu_V(x,y)]}{\sigma_V(x,y)} \quad (1)$$

where $V(x,y,t)$ is the satellite signal measured at time t in some specific spectral band (or in some combination of them) at location (x,y), while $\mu_V(x,y)$ and $\sigma_V(x,y)$ are the so called "*reference fields*" and, respectively, represent the temporal mean and the standard deviation of $V(x,y,t)$ computed at the same location (x,y), using long-term multi-year series of homogeneous (*i.e.* collected during the same time of day and period of year) cloud free satellite records.

According to the particular application, variable $V(x,y,t)$ may be represented by different signals. In the case of RST application to fire detection purposes (RST-FIRES), $V(x,y,t)$ is a "thermal" variable such as the ones suggested in table 1. For each variable, a corresponding ALICE index is computed.

Variable description	Variable V(x,y,t)	ALICE index
the simple brightness temperature measured at location (x,y), at time t, in the medium infrared (MIR) channel	$T_{MIR}(x,y,t)$	$\otimes_{MIR}(x,y,t) \equiv \frac{T_{MIR}(x,y,t) - \mu_{MIR}(x,y)}{\sigma_{MIR}(x,y)}$ (2)
the difference of brightness temperature measured at location (x,y), at time t, in the MIR and thermal infrared (TIR) channels	$\Delta T_{MIR-TIR}(x,y,t) = T_{MIR}(x,y,t) - T_{TIR}(x,y,t)$	$\otimes_{MIR-TIR}(x,y,t) \equiv \frac{\Delta T_{MIR-TIR}(x,y,t) - \mu_{MIR-TIR}(x,y)}{\sigma_{MIR-TIR}(x,y)}$ (3)
the difference between the MIR signal measured at location (x,y), at two contiguous time slots t and t_0 ($t_0 < t$)	$\Delta T_{\Delta tMIR}(x,y,t-t_0) = T_{MIR}(x,y,t) - T_{MIR}(x,y,t_0)$	$\otimes_{\Delta tMIR}(x,y,t-t_0) \equiv \frac{\Delta T_{\Delta tMIR}(x,y,t-t_0) - \mu_{\Delta tMIR}(x,y)}{\sigma_{\Delta tMIR}(x,y)}$ (4)
the difference between the MIR signal measured at location (x,y), at time t, and the mean value of the same signal within a LxL box around the location (x,y), computed excluding cloudy pixels, the pixel under evaluation (x,y) and its nearest neighbours.	$\Delta T_{\Delta sMIR}(x,y,t) = T_{MIR}(x,y,t) - \langle T_{MIR}(x,y,t,L)\rangle$	$\otimes_{\Delta sMIR}(x,y,t) \equiv \frac{\Delta T_{\Delta sMIR}(x,y,t) - \mu_{\Delta sMIR}(x,y)}{\sigma_{\Delta sMIR}(x,y)}$ (5)

Table 1: **Thermal variables and corresponding ALICE indices useful for fire detection.**

TOTAL VALIDATION CAMPAIGNS

Results showed in this paper refer to the RST-FIRES implementation on MSG-SEVIRI data. Indices (2), (4) and (5) of table 1 have been used in a combined way so to identify not only very intense/large fires (thanks to index (2)), but also small events or fires at their starting phase (mainly thanks to indices (4) and (5)). Thermal anomalies detected by RST-FIRES on SEVIRI images have been validated during six campaigns performed in Basilicata Region and in the Palermo Regional Province (Sicily Region) in close collaboration with local authorities and Civil Protection Departments. Differently from usual methods of algorithms validation, the TVA used in these experimental campaigns, permitted actually to confirm the presence (or the absence) of heat sources in correspondence of RST-FIRES based anomalies. In fact, the ground check of detected thermal anomalies permitted us to verify that many of them were in correspondence of small or cleaning fires: in both cases no database would have recorded their occurrence (except in case of a required intervention to extinguish them). This means that an *a-posteriori* validation methodology would have flagged those anomalies as "false alarms", lacking corresponding events in official databases.

In the following, a summary of RST-FIRES performances is presented in terms of reliability and sensitivity, considering all together validation campaigns. In particular, table 2 gives a summary of results concerning RST-FIRES reliability: 948 thermal anomalies were controlled, about 80% ("confirmed anomalies") revealed to be actual fires (in many cases they were small or starting events), about 18% ("not confirmed anomalies") were not confirmed by ground and/or aerial check, about 2% of cases ("other") were generated by other sources (e.g. variations of thermal emission in industrial plants, newly installed photovoltaic panels, inland water bodies,…) which may be eliminated (once and for all) by means of an exclusion map (e.g. Mazzeo et al., 2009).

It is worth highlighting that the present percentage of reliability should be considered as a minimum value because more than once aerial surveys confirmed the presence of fires in correspondence of thermal anomalies which ground check had classified as "not confirmed". This occurred, for example, in cases of fires affecting unreachable or morphologically hidden areas. Therefore, there is some doubt about 17.5% of cases, corresponding to anomalies which were "not confirmed" by ground check (unfortunately, aerial surveys were not always available).

Table 3 summarizes RST-FIRES sensitivity: starting from the total documented fires, events under cloudy conditions and without a precise localization have been excluded (*i.e.* only fires certainly "observable" by a satellite system have been considered); secondly, events producing no MIR SEVIRI signal variations have been excluded (*i.e.* only fires "identifiable" by the SEVIRI sensor have been considered). The percentage of "identified events" (71%) is so referred only to the identifiable ones.

<table>
<tr><th colspan="14">RELIABILITY</th></tr>
<tr><th rowspan="2">VALIDATION CAMPAIGN</th><th rowspan="2">NUMBER OF DAYS</th><th rowspan="2">TOTAL CONTROLED ANOMALIES</th><th rowspan="2" colspan="2">CONFIRMED ANOMALIES</th><th colspan="8">NOT CONFIRMED ANOMALIES</th><th rowspan="2" colspan="2">OTHER</th></tr>
<tr><th colspan="2">TOTAL</th><th colspan="2">by ground check</th><th colspan="2">by ground and aerial check</th><th colspan="2">by aerial check</th></tr>
<tr><td>ALL</td><td>267</td><td>948</td><td>756</td><td>79,75%</td><td>172</td><td>18,14%</td><td>166</td><td>17,51%</td><td>1</td><td>0,10%</td><td>5</td><td>0,53%</td><td>20</td><td>2,11%</td></tr>
</table>

Table 2: **RST-FIRES performances in terms of reliability. They are a summary of all validation campaigns.**

<table>
<tr><th colspan="7">SENSITIVITY</th></tr>
<tr><th>VALIDATION CAMPAIGN</th><th>NUMBER OF DAYS</th><th>TOTAL DOCUMENTED EVENTS</th><th>OBSERVABLE EVENTS</th><th>IDENTIFIABLE EVENTS</th><th colspan="2">IDENTIFIED EVENTS</th></tr>
<tr><td>ALL</td><td>256</td><td>2385</td><td>1566</td><td>1230</td><td>874</td><td>71.1%</td></tr>
</table>

Table 3: **RST-FIRES performances in terms of sensitivity. They are a summary of all validation campaigns.**

The results which we obtained applying RST-FIRES to MSG-SEVIRI data during such campaigns have been compared to other satellite-based fire products: FIR (EUMETSAT, 2010), FD&M (EUMETSAT LSA SAF, 2009; Amraoui et al. 2010) and SFIDE (Laneve et al., 2006). FIR and FD&M are EUMETSAT products and they are directly acquired at the EUMETCast station of University of Basilicata; missing FD&M data have been ordered by means of LAND SAF website (2013). SFIDE is freely available on-line by means of a plug-in which may be downloaded by CRPSM website (2013). All of them are fire products based on MSG-SEVIRI data so that a direct comparison is possible. In the following tables, a comparative analysis of sensitivity is presented for RST-FIRES, FIR (table 4), FD&M (table 5) and SFIDE (table 6). Since comparative products were available only during some periods of the campaigns, the comparison with RST-FIRES is made during days of their availability. For sake of completeness, each table (one for each comparative product) indicates validation campaign, number of days used for comparison, total documented events as well as “observable” and “identifiable” fires during the period of comparison.

It is evident from tables 4, 5, and 6 that percentages of correctly identified events may vary from one campaign to another. It may depend, for example, on the number of thermal anomalies which were checked on the field: the greater number of checks, the larger percentage of identified fires. Palermo campaign 2010 is emblematic, when RST-FIRES reached the highest values of identified events (98.6 %) thanks to a great effort of POPs (provincial operative garrisons). Any case, it is quite evident the large difference in sensitivity between RST-FIRES and the other algorithms. Figure 1 resumes performances of RST-FIRES versus other SEVIRI-based algorithms (values reported are the red percentages of tables 4, 5, and 6).

VALIDATION CAMPAIGN	**NUMBER OF DAYS**	***TOTAL DOCUMENTED EVENTS***	***OBSERVABLE EVENTS***	***IDENTIFIABLE EVENTS***	***IDENTIFIED by RST-FIRES***		***IDENTIFIED by FIR***	
Basilicata 2010	38	610	323	182	133	73.1%	6	3.3%
Palermo 2010	42	187	149	146	144	98.6%	9	6.2%
Palermo 2011	76	212	212	212	149	70.3%	13	6.1%
Basilicata 2012	18	415	283	243	104	42.8%	4	1.6%
RST vs FIR	**174**	**1424**	**967**	**783**	**530**	**67.7%**	**32**	**4.1%**

Table 4: **RST-FIRES vs FIR. Validation campaigns, days of validation, total documented events, observable events, together with events identified by RST-FIRES and FIR respect to the identifiable events.**

VALIDATION CAMPAIGN	***NUMBER OF DAYS***	***TOTAL DOCUMENTED EVENTS***	***OBSERVABLE EVENTS***	***IDENTIFIABLE EVENTS***	***IDENTIFIED by RST-FIRES***		***IDENTIFIED by FD&M***	
Palermo 2011	22	131	131	131	89	67.9%	2	1.5%
Basilicata 2012	18	415	283	243	104	42.8%	2	0.8%
RST vs FD&M	**40**	**546**	**414**	**374**	**193**	**51.6%**	**4**	**1.1%**

Table 5: **RST-FIRES vs FD&M. Validation campaigns, days of validation, total documented events, observable events, together with events identified by RST-FIRES and FD&M respect to the identifiable events.**

VALIDATION CAMPAIGN	***NUMBER OF DAYS***	***TOTAL DOCUMENTED EVENTS***	***OBSERVABLE EVENTS***	***IDENTIFIABLE EVENTS***	***IDENTIFIED by RST-FIRES***		***IDENTIFIED by SFIDE***	
Basilicata 2010	38	610	323	182	133	73.1%	42	23.1%
Palermo 2010	42	187	149	146	144	98.6%	33	22.6%
Palermo 2011	71	211	211	211	149	70.6%	37	17.5%
Basilicata 2012	18	415	283	243	104	42.8%	9	3.7%
RST vs SFIDE	**169**	**1423**	**966**	**782**	**530**	**67.8%**	**121**	**15.5%**

Table 6: **RST-FIRES vs SFIDE. Validation campaigns, days of validation, total documented events, observable events, together with events identified by RST-FIRES and SFIDE respect to the identifiable events.**

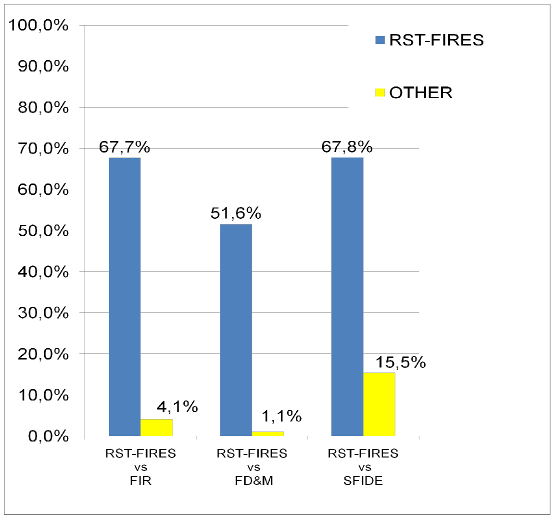

Figure 1: **Histogram resuming performances of RST-FIRES vs other SEVIRI-based fire products (FIR, FD&M, SFIDE).**

CONCLUSIONS

Performances of the RST-FIRES algorithm, implemented on MSG-SEVIRI data, have been presented both in terms of sensitivity and reliability, on the basis of an original validation method (Total Validation Approach). TVA permitted us to verify that RST-FIRES thermal anomalies corresponded to large fires as well as to other events which usually are not recorded in official registers due to their size (small fires not requiring intervention) or nature (*e.g.* cleaning fires).
The high sensitivity of RST-FIRES (about 71% on average; up to 98% during 2010 validation campaign in Palermo Regional Province), together with a remarkable reliability (not less than 80%), actually supported civil protection brigades in rapidly (within 15 minutes) locating fires so that they were able to extinguish starting fires, to control burning stubbles until their self-extinguishing, to face fires before reaching protected areas and even to catch pyromaniacs in action. The experimental campaigns, initially planned only to assess RST-FIRES algorithm, proved that Civil Protection may really benefit of geostationary satellite sensors with high temporal resolution like MSG-SEVIRI, provided that a suitable fire detection algorithm is used. The comparison with other SEVIRI-based algorithms clearly showed that, satellite data being equal, RST-FIRES sensitivity is tens of percentage points greater. Taking the above-mentioned performances in mind, it is so expected that the combined use of the RST-FIRES algorithm and MSG-SEVIRI data acquired in rapid scanning mode (5-min repetition rate) further increases support to civil protection activities.

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