THE SAF FOR LAND SURFACE ANALYSIS
WILDFIRE APPLICATIONS

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Abstract

Fire-related processes have long been identified as applications with great potential to be derived from SEVIRI/Meteosat and AVHRR/Metop. The set of applications range from pre-fire signal, which merged with meteorological parameters provide indicators of fire risk, up to fire detection and monitoring and fire scar identification. The severity of wildfire-related problems, together with the demands from environment monitoring and risk management (*e.g.*, GMES requirements) and a growing number of users in agricultural and forestry applications has led EUMETSAT's Satellite Application Facility for Land Surface Analysis (LSA SAF) to commit to the development of two new lines of research aiming to explore the capability of SEVIRI/Meteosat to detect and monitor (i) active fires and (ii) signals of vegetation stress, following its variability in space and time. The first line of research relates to the operational generation, archiving and dissemination, particularly over Africa, of the so-called Fire Detection and Monitoring (FD&M) product, whereas the second line is related to the so-called Risk of Fire Mapping (RFM) and aims to derive danger of fire rating and operationally produce maps of fire risk for (Southern) Europe.

INTRODUCTION

The main purpose of the Satellite Application Facility (SAF) on Land Surface Analysis (LSA) is to take full advantage of remotely sensed data, particularly those available from EUMETSAT sensors, to describe/derive land surface properties/variables (LSA SAF, 2006). After successfully completing the Development Phase (June 1999 – December 2004) and the Initial Operational Phase (January 2005 – February 2007), the LSA SAF has started, in March 2007, its Continuous Development and Operations Phase (CDOP) that is planned to last until February 2012.

The LSA SAF products are relevant to a wide range of applications and, since the beginning of its scientific and technical activities, particular attention has been devoted to the end-user community (Tavares and DaCamara, 1999). Although the Numerical Weather Prediction (NWP) community has been identified as having the greatest potential to fully exploit the LSA SAF products and was therefore assigned the highest priority during the Development Phase (DaCamara and Tavares, 2001), the LSA SAF addresses a much broader community (Tavares and DaCamara, 2002), including amongst others agricultural and forestry applications and natural hazard management. Whereas agricultural and forestry applications require information on soil and vegetation properties, natural hazard management requires frequent observations of terrestrial surfaces in both the solar and thermal bands together with merged information from NWP models and surface characteristics (DaCamara, 2006). In this particular, fire-related processes appear as especially relevant since they have long been identified as applications with great potential to be derived from SEVIRI/Meteosat and AVHRR/Metop (Pereira and Govaerts, 2001).

With the aim of responding adequately to demands on environment monitoring and risk management (e.g., GMES requirements), the LSA SAF Team has initiated a new line of research related with forest fire applications. The new products are expected to be mostly developed during the first two years of the CDOP and the rationale is to begin exploring the capability of SEVIRI/Meteosat and AVHRR/Metop to detect and monitor:

- active fires, particularly over Africa, leading to the operational dissemination of the Fire Detection and Monitoring (FD&M) product;
- signals of heat and water stress on vegetation for Southern Europe, leading to the operational dissemination of the Risk of Fire Mapping (RFM) product.

THE FIRE DETECTION AND MONITORING PRODUCT

Biomass burning is a significant global source of greenhouse gases (e.g. carbon dioxide and methane) as well as of nitric and carbon monoxides, methyl bromide and hydrocarbons that lead to acid rain and the photochemical production of tropospheric ozone and destruction of stratospheric ozone which impact global climate (e.g. Crutzen and Andreae, 1990). Other impacts of biomass burning relate to the biogeochemical cycling of nitrogen and carbon compounds, the hydrological cycle, the reflectivity and emissivity of the land, the stability of ecosystems and ecosystem biodiversity (e.g. Dwyer, et al. 1999).

Instituto Dom Luiz (IDL, University of Lisbon) is currently responsible for the development of a contextual algorithm for active fire detection based on information from MSG channels (namely the 0.6 µm, 0.8 µm, 3.9 µm, 10.8 µm and 12.0 µm) together with information on illumination and viewing angles. Choice of a contextual algorithm was motivated by the aim of detecting active fires without having to adjust the algorithm for the different geographical regions. When compared with conventional channel-threshold techniques, contextual algorithms have shown better performance and consistency at both the continental and global levels.

The method is based on contextual algorithms that have been successfully developed for different sensors, namely GOES, NOAA-AVHRR and MODIS (e.g. Prins *et al.*, 1998; Giglio *et al.*, 1999; Stroppiana *et al.*, 2000; Justice *et al.*, 2002). The method consists of the following steps:

1^{st} step – Masks of water bodies and desert regions

Pixels associated to water bodies and desert regions are eliminated using maps of land cover (GLC 2000) as provided by the LSA SAF.

2^{nd} step – Selection of potential fire pixels

A given pixel is considered as a potential fire pixel if one of the following conditions (*e.g.* Justice *et al.*, 2002) is fulfilled:

$$\left[(\mathrm{TB}(3.9) \geq 315\mathrm{K}) \cap (\mathrm{TB}(3.9) - \mathrm{TB}(10.8) \geq 10\mathrm{K})\right] \quad \text{at day time}$$
$$\left[(\mathrm{TB}(3.9) \geq 305\mathrm{K}) \cap (\mathrm{TB}(3.9) - \mathrm{TB}(10.8) \geq 3\mathrm{K})\right] \quad \text{at night time}$$

where TB(3.9) and TB(10.8) are brightness temperatures of SEVIRI channels 3.9 µm and 10.8 µm and day (night) times are associated to solar zenith angles lower than or equal to (larger than) 85º.

3^{rd} step – Cloud mask

A given pixel is considered as associated to or contaminated by clouds and therefore eliminated if one of the following conditions (*e.g.* Saunders and Kriebel, 1988) is fulfilled:

$$[R(0.6) + R(0.8) > 1.2] \cup [TB(12) < 265K] \cup$$
$$[(R(0.6) + R(0.8) > 0.8) \cap (TB(12) < 285K)]$$

at day time

$$[TB(12) < 265K]$$

at night time

where R(0.6) and R(0.8) are refectances of SEVIRI channels 0.6 µm and 0.8 µm, TB (12) are brightness temperatures of SEVIRI channel 12.0 µm, and day and night times are defined as in the 2nd step.

4th step – Mask of highly reflective surfaces

A given pixel is considered as associated to a highly reflective surface and therefore eliminated if the following condition (Stroppiana *et al.*, 2000) is fulfilled during daytime (as defined in the 2nd step):

$$[R(0.8) \geq 0.20]$$

where R(0.8) are refectances of SEVIRI channel 0.8 µm.

5th step – Mask of pixels affected by sun glint

A given pixel is considered as contaminated by sun glint and therefore eliminated if the following condition (Giglio *et al.*, 2003) is fulfilled during daytime (as defined in the 2nd step):

$$[\theta_g < 5°] \cup [(\theta_g < 15°) \cap (R(0.8) > 0.2)]$$

where θ_g is the sun glint angle and R(0.8) are refectances of SEVIRI channel 0.8 µm.

6th step – Confirmation of potential fire pixel

For every potential fire pixel (as identified in the 2nd step) a 5×5 grid is considered (centered at the considered potential fire pixel) and the following statistics are computed over the background pixels, *i.e.* all pixels inside the grid that were neither identified as potential fire pixels (in the 2nd step) nor masked because of contamination by clouds, reflective surfaces or sun glint (in the 3rd, 4th and 5th steps):

$$\overline{TB}(3.9) = \frac{1}{N}\sum_{i=1}^{N}[TB_i(3.9)]$$ *i.e.* the average of TB(3.9),

$$\delta(3.9) = \frac{\sum_{i=1}^{N}\left|TB_i(3.9) - \overline{TB}(3.9)\right|}{N}$$ *i.e.* the absolute mean deviation of TB(3.9),

$$\overline{\Delta T} = \frac{1}{N}\sum_{i=1}^{N}\Delta T_i, \quad \Delta T_i = TB_i(3.9) - TB_i(10.8)$$

i.e. the mean difference between TB(3.9) and TB(10.8),

$$\delta(\Delta T) = \frac{\sum_{i=1}^{N}\left|\Delta T_i - \overline{\Delta T}\right|}{N}$$ *i.e.* the absolute mean of ΔT

It may be noted that the above statistics are only computed when the number of pixels of the background exceeds 3 pixels and represents more than 25% of the pixels that were not masked in the grid (according to the procedures described in the 3rd, 4th and 5th steps). When such is not the case the active fire pixel is labelled as unclassified.

A potential fire pixel is classified as an active fire pixel if one of the following conditions (*e.g.* Giglio *et al.*, 1999) is fulfilled:

$$\left[TB_{PF}(3.9) > \overline{TB}(3.9) + \delta(3.9) - 3\right] \cap \left[\Delta T_{PF} > \overline{\Delta T} + MAX(2{,}5 * \delta(\Delta T), 4)\right] \quad \text{at day time}$$

$$\left[\Delta T_{PF} > \overline{\Delta T} + \max(2{,}5 * \delta(\Delta T), 4)\right] \quad \text{at night time}$$

where day and night times are as defined in the 2nd step.

Figure 1 presents an example of results as obtained from the application of the developed algorithm over the Northern African (January 2007) and the Southern African (July 2007) windows of the LSA SAF.

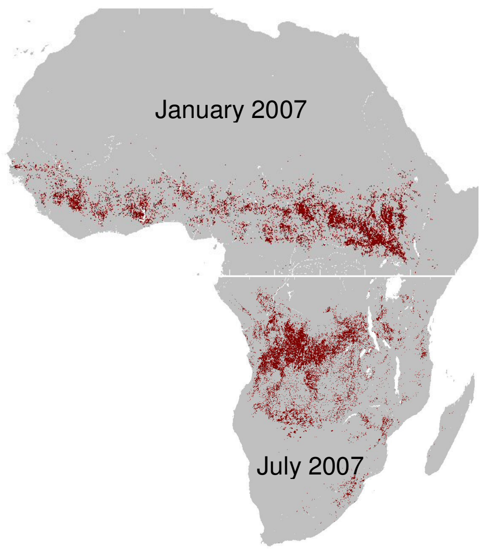

Figure 1. **Active fires over the Northern African (375,780 events) and the Southern African (320,664 events) windows, respectively during January and July 2007. Active fires were identified using information from SEVIRI every 15 minutes and on a pixel by pixel basis.**

Validation of results is based on the assessment of internal consistency of obtained results as well as on the inter-comparison of results as obtained from different algorithms and/or different instruments. Internal consistency includes characterizing the number of fire events as a function of the respective duration (Figure 2) and the daily cycle of fire activity for different types of land cover (Figure 3).

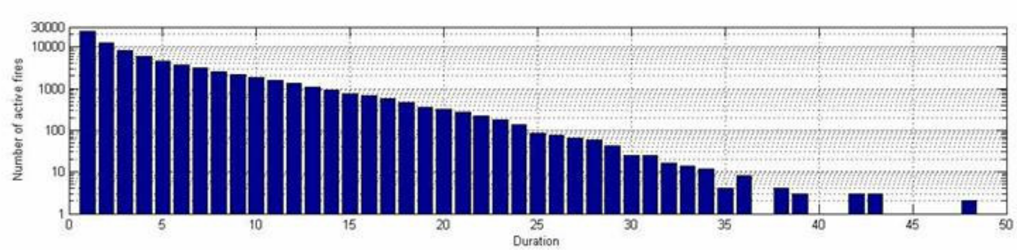

Figure 2. **Number of fire events as a function of the respective duration over the Southern African window during July 2005. Duration is expressed in units of MSG slots (*i.e.* on a15 minute repeat cycle).**

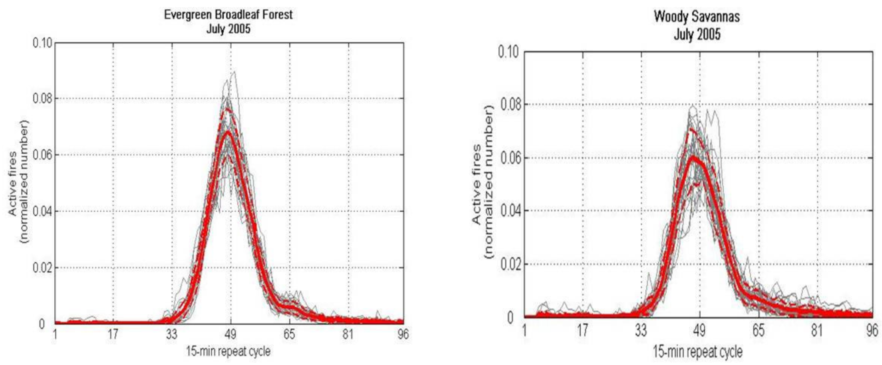

Figure 3.**Daily cycles of fire activity for pixels classified as belonging to "evergreen broadleaf forest" (left panel) and "woody savannas" (right panel). The analysis was performed during July 2005 over the Southern African window. Duration is expressed in units of MSG slots (*i.e.* 15 minute repeat cycle) and number of pixels is normalised by the daily total. The thick red solid line represents the monthly average and the two thick red dashed lines delimit the one-standard deviation interval.**

Inter-comparison of results will take into consideration the following sources:

- the GOFC/GOLD (Global Observations of Forest Cover and Land Cover Dynamics) Fire Program (http://gofc-fire.umd.edu/) project of the Global Terrestrial Observing System (GTOS) program, which is sponsored by the Integrated Global Observing Strategy (IGOS);
- the MODIS fire and thermal anomalies products (http://modis-fire.umd.edu/index.asp) which will provide an important contribution to the NASA Land Use and Land Cover Program and the International Global Observation of Forest Cover (GOFC) Project;
- The AFIS (Advanced Fire Information Service) from the CSIR-Meraka Institute (South Africa) that aims to provide information regarding the prediction, detection and assessment of fires in Africa using Remote Sensing and GIS technology (http://divenos.meraka.csir.co.za/afis/afis.html);
- The Active Fire Monitoring (FIR) product from EUMETSAT that is an image-based product (http://www.eumetsat.int/Home/Main/Access_to_Data/Meteosat_Meteorological_Products/Product_List/SP_1145431848902?l=en) in MSG full pixel resolution that displays information on the presence of fire within a pixel.

THE RISK OF FIRE MAPPING PRODUCT

Wildfires are a major concern in Europe, especially in Mediterranean countries, where warm and dry summers may lead to high levels of vegetation stress (Chuvieco et al., 1997). During summer months, the Mediterranean countries suffer frequent large-scale fire episodes with dramatic consequences for the ecosystems and population but late winter and spring fires should not be disregarded in some southern European areas.

The aim is to develop a fire risk index at the European regional level by making an optimal usage of meteorological observations and forecasts combined with land surface parameters derived from MSG and NOAA/EPS. During a first phase the index will be derived over Continental Portugal because of the previous experience of the IDL team as well as of the availability of time series of fire events and burnt areas and of associated meteorological conditions.

Time series of burnt area in Portugal (Figure 4) show a positive trend since the early 80's together with a large inter-annual variability. Whereas the observed increase in burnt area is partially attributable to changes in farming and land use, inter-annual variability is partly due to the temperature and precipitation conditions in the preceding late spring season and partly to the occurrence of atmospheric circulation patterns of short-duration (Figure 5) that induce extremely hot and dry spells over western Iberia (Figure 6).

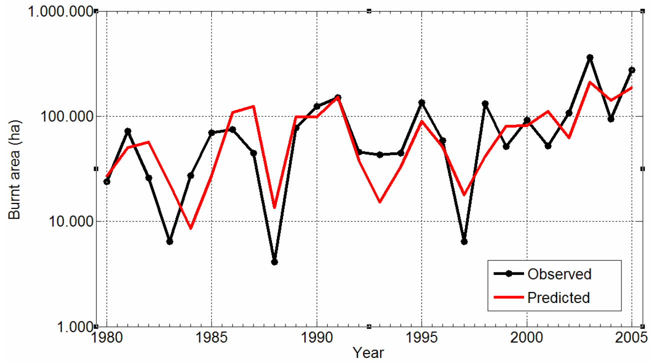

Figure 4.**Time series for the period 1980-2005 of the logarithm of the cumulated burnt area in July and September over Continental Portugal. Observed values were extracted from the official data base of the Directorate-General of Forests (DGF). Predicted values are results from the cross-validation of a multi-linear regression model using as predictors the average temperature and the cumulated precipitation of the preceding months of May and June. The correlation coefficient between the two curves is 0.75.**

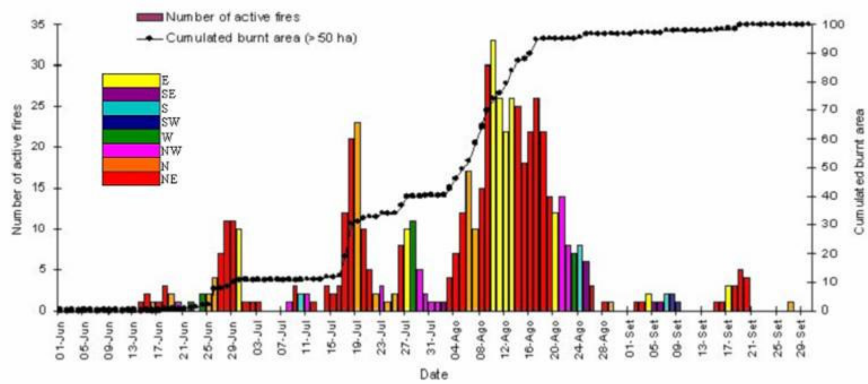

Figure 5.**Time series of daily fire occurrences (vertical bars) corresponding to burnt areas greater than 50 ha and respective cumulated values of daily burnt area (black solid line). Colour of bars indicates the observed direction of predominant wind (from Calado, 2004).**

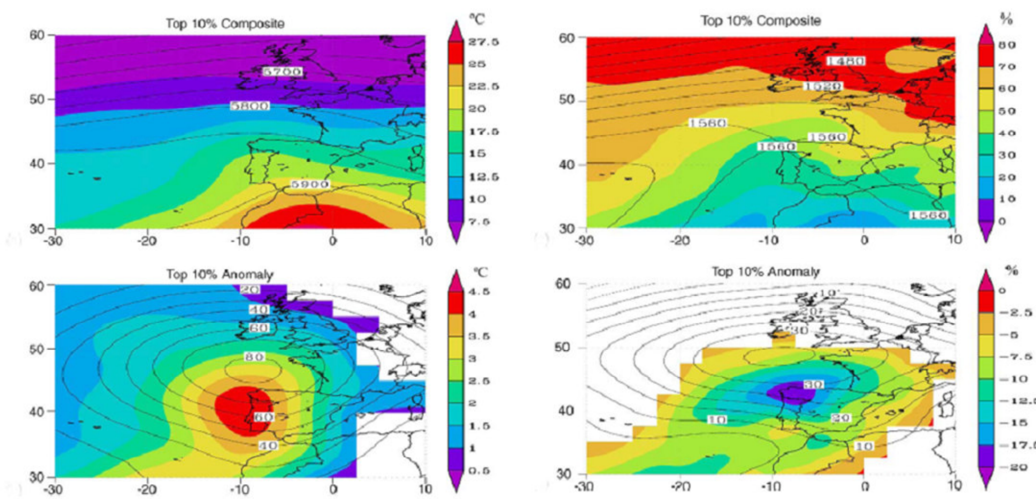

Figure 6. **Left panels: Air temperature fields (ºC), at 850 hPa, for (upper panel) composite for the 10% highest burnt area days in Portugal and (lower panel) the corresponding 10% anomaly. Right panels: As in left panels but respecting to relative humidity (%) at 850 hPa. Contour lines show the corresponding geopotential height (gpm), respectively at 500 hPa for air temperature and 850 hPa for relative humidity. Climate anomaly fields are represented only in those areas where such anomaly is significant at the 1% level (or 99% confidence level) computed with a two-tailed t-test. The analysis respects to the period 1980-2000 (from Pereira et al., 2005).**

The procedure currently being developed for fire risk assessment consists of two main steps; the first one deals with the background conditions associated to the structural risk and to the stress of vegetation according to the late spring temperature and precipitation conditions, whereas the second step deals with meteorological conditions that favour the onset and propagation of wildfires.

Structural risk (*e.g.* Chuvieco and Congalton, 1989) is assessed by means of a set of variables related to long-term fire hazard that range from fuel structure and terrain characteristics to human activities and climate variability. Choice of relevant variables and evaluation of structural risk involves studying statistical relationships between long-term records of variables and fire events. Heat and water stress of vegetation involves the development of statistical models that relate the amount of burnt area during the fire season with averages of relevant meteorological parameters over a certain period that precedes the fire season. For instance, about 50% of observed inter-annual variability of the logarithm of cumulated burnt area in July and August over Continental Portugal is explained by the average temperature and the cumulated precipitation in the previous months of May and June (Figure 4).

Meteorological factors play a crucial role in the setting and spreading of wildfire and are an important factor in the resulting fire severity (e.g. Bovio and Camia, 1997). In Portugal, a large amount (circa 80%) of the burnt area is due to fire events that occurred on a very small number (circa 10%) of summer days (Pereira *et al.*, 2005). Forest fires in Portugal occur when the atmospheric circulation forms a prominent ridge over the Iberian Peninsula (Figure 6). Near the surface, wind and sea level pressure anomalies show that these days are associated with south-easterly conditions (Figures 5 and 6), with a strong anomalous advection from northern Africa that is further heated when crossing the central Iberian plateau.

Meteorological variables alone or combined with vegetation and topographical information are frequently used to develop fire risk indices, such as the Canadian Fire Weather Index, FWI (van Wagner, 1987). Fire risk indices may be based on single or combined use of meteorological station measurements, weather forecast model outputs and remote sensing estimations. Han et al. (2003) have shown that a regional estimation of FWI over Quebec (Canada) showed the best fit when computed using a combination of meteorological station measurements and remote sensing derived surface temperature and humidity; on the other hand more precise results (i.e. with lower normalized root mean square errors) were produced when combining weather forecast model outputs with remote sensing estimations.

The LSA SAF Consortium will contact directly National Environmental and Civil Protection Agencies to ask for feedback on the adequacy of fire-risk related products. In particular, the LSA SAF will involve the Portuguese Civil Protection, which already collaborates regularly with the Portuguese Meteorological Institute (IM) to produce forecasts of fire indices, in the identification of requirements for the Risk of Fire Mapping (RFM) product.

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