Abstract

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. 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.

The potential of the SEVIRI instrument on-board the MSG series for applications related to fire detection and monitoring has long been recognized. We present an operational procedure for active fire detection based on information from Meteosat-8/SEVIRI, which is currently being developed within the framework of the Satellite Application Facility on Land Surface Analysis (LSA SAF). The procedure primarily relies 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. The method is based on contextual algorithms that have been successfully developed for different sensors, namely GOES, NOAA-AVHRR and MODIS. A potential fire pixel is compared with the neighbouring ones and the decision is made based on relative thresholds as derived from the pixels in the neighbourhood. The algorithm is self-adaptive and has shown consistency over large areas and throughout the seasons.

We will present an overview of results obtained for 2007, paying special attention to the duration of wildfires as well as to daily and weekly cycles of wildfire activity over different regions and for different types of land cover. Quality of results will be assessed by means of a set of tests applied under various conditions and to different ecosystems and by comparing obtained results with those from other sources, namely: i) the MODIS fire and thermal anomalies products, ii) burnt area maps from L3JRC of SPOT VGT and iii) the AFIS (Advanced Fire Information Service) from the CSIR-Meraka Institute (South Africa).

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 and the Initial Operational Phase, 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, the LSA SAF team has developed a new line of research related with forest fire applications. The new product is expected to be mostly developed during the first two years of CDOP and the rationale is to investigate the capability of SEVIRI/Meteosat to detect and monitor active fires, particularly over Africa, leading to the operational generation, archiving and dissemination of the so called Fire Detection and Monitoring (FD&M) product.

THE FD&M PRODUCT

The fire detection method consists of a contextual algorithm that relies on different procedures that have been successfully applied to different sensors, namely GOES, NOAA-AVHRR and MODIS (Flasse and Ceccato 1996, Prins et al., 1998, Giglio et al., 1999, Stroppiana et al., 2000, Justice et al., 2002, Giglio et al., 2003). It may be noted that contextual algorithms avoid having to adjust the algorithm for each geographic region and have shown better performance and global consistency when compared with conventional channel-threshold techniques (Giglio et al., 1999).

As shown in Table 1, the algorithm uses top of the atmosphere radiances from several channels of the SEVIRI instrument. Infrared channels IR3.9 and IR10.8 are used for active fire detection, whereas infrared channel IR12.0 is employed for cloud detection. The red VIS0.6 channel is used for cloud detection and the near-infrared channel VIS0.8 is used for both cloud detection and for rejecting bright surfaces and pixels contaminated by sun glint.

Table 1. SEVIRI Channels used in the developed algorithm.

<table>
<thead>
<tr>
<th>Channel</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>VIS 0.6</td>
<td>Cloud detection</td>
</tr>
<tr>
<td>VIS 0.8</td>
<td>Cloud detection, bright surface, sun glint rejection</td>
</tr>
<tr>
<td>IR 3.9</td>
<td>Active fire detection</td>
</tr>
<tr>
<td>IR10.8</td>
<td>Active fire detection</td>
</tr>
<tr>
<td>IR12.0</td>
<td>Cloud detection</td>
</tr>
</tbody>
</table>

Surfaces such as exposed soil and rock, which are highly reflective at 3.9 μm, may be the source of false fire detections. In order to mitigate these effects, a land-water mask is used to exclude inland water bodies (including rivers and lakes) as well as pixels along the coastlines. The desert mask is employed to eliminate highly reflective surfaces and to reduce needless processing in hot regions where burning is not likely to occur. It is worth mentioning that the identification of pixels associated to water bodies, desert regions and urban zones was based on the Global Land Cover (GLC2000) as provided by the LSA SAF. Pixels associated to volcanoes were also excluded using the Global Volcanism Program (http://www.volcano.si.edu).

The algorithm starts by looking for pixels that are likely to contain an active fire. For this purpose, simple thresholds tests are applied, on a pixel by pixel basis, to both channels IR3.9 and IR10.8. A given pixel is accordingly classified as a potential fire pixel if the following two criteria are simultaneously satisfied: high values of brightness temperature in the IR3.9 channel and high values of the difference between brightness temperatures of both IR3.9 and IR10.8 channels (Figure 1).

Several tests are then performed in order to prevent false alarms; for instance, every pixel which is contaminated by clouds, by high reflectivity or by sun glint is considered as a false alarm and is eliminated (Figure 2).

Each pixel that surpasses all the above-mentioned tests is then subject to a contextual test which computing a set of statistics for channels IR3.9 and IR10.8 within a fixed 5x5 pixel window, centered on the pixel under consideration. A potential fire pixel is confirmed as a fire
pixel, if it is much warmer than the background pixels within the window. All data processing stages for spatial fire detection algorithm are summarized in the Figure 3.

Figure 1. Potential fire as detected by the developed algorithm.

Figure 2. False alarms as detected by the developed algorithm. Clouds, highly reflective surfaces and pixels contaminated by sun glint are respectively shown in blue, yellow and red.

Figure 3. Flow diagram of the spatial component of the fire detection algorithm.
Figure 4. Active fires over the Northern African the Southern African 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.

Pixels identified as containing an active fire are finally subject to, a temporal test that aims at eliminating short-lived fires that are also likely to be false alarms. A non-persistent fire pixel (i.e. an isolated pixel in space and time) is considered as a false alarm and eliminated. Figure 4 and Table 2 give an overview of results that were obtained from the application of the developed algorithm to the Northern African window in January 2007 and to the Southern African window in July 2007.

Table 2.

<table>
<thead>
<tr>
<th>Vegetation</th>
<th>Northern Africa</th>
<th>Southern Africa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instantaneous fires</td>
<td>370239</td>
<td>325923</td>
</tr>
<tr>
<td>Fire pixels</td>
<td>64531</td>
<td>67350</td>
</tr>
<tr>
<td>Single occurrence</td>
<td>19581</td>
<td>15132</td>
</tr>
<tr>
<td>Sparse herb./shrub.</td>
<td>8857</td>
<td>20</td>
</tr>
</tbody>
</table>

RESULTS AND DISCUSSION

Obtained results were validated by checking for internal consistency and by performing a comparison with similar results obtained from different algorithms and/or different instruments.

Checks for internal consistency include characterizing the duration of active fires, studying the diurnal cycle of fire activity and identifying other spatial and/or temporal characteristics. Figure 5 presents the number of identified events as a function of the respective duration for both the Northern African and the Southern African windows. The exponential decay of number of active fires with duration is worth being noted, as well as the similar behaviour of the two windows. Figure 6 presents the daily cycle of fire activity for different types of land cover over the Southern African window. Although the amplitude of the daily cycles depend on vegetation type,
there is always a well-pronounced maximum around 14 hours (local time). Figure 7 presents the observed weekly cycles of active fires over several African regions associated to a predominant religion. There is a clear relationship between fire activity and local religion; areas where Muslim population dominates present a minimum of fire activity on Fridays whereas regions that are mostly Christian have a minimum on Sundays. Regions dominated by animism do not show any significant changes in fire activity along the week.

Figure 5. Number of fire events as a function of the respective duration over the Northern and the Southern African windows, respectively during January and July 2007. Duration is expressed in units of MSG slots (i.e. on a 15 minute repeat cycle).

Figure 6. Daily cycles of fire activity over the Southern African window during July 2007 (upper left panel), for pixels classified as belonging to “Tree cover, broadleaved, deciduous, closed” (upper right panel), for pixels classified as belonging to “Tree cover, broadleaved, deciduous, open” (button left panel) and for pixels classified as “shrub cover, closed-open, deciduous” (button right panel). The number of pixels is normalized by the daily total. The thick blue solid line represents the monthly average and the two thick blue dashed lines delimit the one-standard deviation interval.
The following three sources of information were taken into account for comparison purposes:

- The MODIS fire and thermal anomalies products (http://modis-fire.umd.edu/index.asp);
- Burnt area maps from L3JRC SPOT VGT;
- Hot spots from the Advanced Fire Information Service (AFIS) of the CSIR-Meraka Institute in South Africa. (http://divenos.meraka.csir.co.za/afis/afis/html).

One of the procedures of comparison involves considering the region of interest (Northern African window) as being subdivided using a set of grids of different sizes. For each grid size correlations $R$ were computed between fires detected by SEVIRI (LSA SAF product) and MODIS and between fires detected by SEVIRI (LSA SAF product) and burnt area of L3JRC.

Figure 8 shows a similar behavior of $R$ as a function of grid size for both MODIS fire and L3JRC burnt area. For small grid sizes the correlations are not satisfactory. However, larger grid sizes, e.g. 12x12 pixels and larger, have similar correlation coefficients. The grid size of 12x12 pixels seems therefore as the more appropriate spatial scale for comparing results from SEVIRI with those from polar-orbit sensors (MODIS and SPOT Vegetation in this case).

The second procedure involves the comparison of results obtained using two different algorithms, i.e. comparing the LSA SAF and the AFIS products, both based on raw information.
from the SEVIRI instrument. Both the spatial distribution and the temporal evolution of the two products were compared.

Figure 9 presents the results that were obtained using the two algorithms for the 15-minute time series for July 27 and 28, 2007. The blue curve refers to results using the LSA SAF algorithm. The spatial distribution is given in the lower panel by the red dots. Bare areas and sparsely vegetated regions are presented in gray and brown and it may be noted that no fires are present in these regions because of the developed filtering process.

The red curve refers to the AFIS results and two secondary maxima may be noted around 15 hours. These maxima are not present in the LSA SAF results. The spatial distribution is given in the bottom left panel and it may be noted that there is a large number of fires over bare and sparsely vegetated areas. It is also worth noting that the AFIS algorithm uses a lower threshold than the LSA SAF algorithm.

In order to make the two time series comparable, the AFIS results were modified by filtering out hot spots over bare and sparsely vegetated areas or associated to lower brightness temperatures lower than the thresholds prescribed by the LSA SAF algorithm. The new results are given by the green curve and the spatial distribution may be seen in the bottom right panel. The secondary peaks have disappeared and the overall agreement between the two algorithms is now well apparent.

Differences in the two algorithms may be attributed to the different aims of the LSA SAF and the AFIS products. In the AFIS case, the aim is to protect the electrical system and the algorithm is more prone to false alarms. In the LSA SAF case, the algorithm is more conservative because it was designed to applications related to CO$_2$ emissions.
REFERENCES


