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Monitoring the amount of carbon released into the atmosphere in Portugal due to forest fires, in the summer of 2013

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Abstract

Forest fires are one of the most devastating natural disasters occurring in Portugal mainland over the summer season, with a strong impact on the economy, environment and climate. In last four decades the increase of wildfires problems in Portugal linked to Industrialization, urbanization, rural exodus (in recent past), and emigration (nowadays), with tendency to be worst in the future, lead to a mutation in Portuguese society. Severity of wildfires its worst year to year, besides the effort of the State, increasing human, operational, technical and economic resources to solve the problem. The fire combat continue very difficult and the number of occurrences of fires getting out of control, becoming larger and larger with a heady impact the increase of destruction.

Present work aim to contribute to a development of a support decision tool to be used in combat operations, monitoring fire spots and fire evolution using LSA SAF (*Land Surface Analysis Satellite Application Facilities*) products. The FRP (*Fire Radiative Power*) a product of LSA SAF are available and free distributed, in NRT (*Near Real Time*) and off-line, every 15 minutes for all pixels with a delay of about 20 minutes. These data can, subsequently, be used to obtain the carbon (or the equivalent CO_2), estimated for each pixel and integrated for a given area and period of time or, simply, to map and monitor forest fires.

This work is showing the possibility of monitoring forest fires, using FRP product with about 4 km of spatial resolution, taking advantage of the very interesting temporal resolution (15 minutes). As test, two major wildfires of 2013 had been used: Alfândega da Fé (Picões), from 8 to 11 July, and another one, in the region of Caramulo, from 21 to 30 August. Burnt area was, respectively, 14000 ha and 9416 ha, according data provide *by ICNF.*

Keywords: carbon release; monitoring forest fires; meteorological satellites; LSA; SAF; EUMETSAT

1. Introduction

The spectral characteristics, temporal resolution and coverage of meteorological satellites, allow, in addition to weather monitoring, surveillance and forecast, the use of data in other areas of activity, such as climate monitoring, agriculture and forestry support, namely, on forest fires monitoring.

The operation of the European System of Geostationary Satellites (METEOSAT SECOND GENERATION – MSG) is under the responsibility of EUMETSAT (https://www.eumetsat.int/). EUMETSAT ground segment includes, not just a central unity, *Central Application Facility* (CAF), but also, several different centres for satellite applications, *Satellite Application Facilities* (SAF).

The Portuguese Sea and Atmosphere Institute (IPMA) is responsible for the *Land Surface Analysis Satellite Application Facilities* (LSA SAF), ensuring the development of algorithms for obtaining various biophysical parameters on the ground, such as descendant radiative fluxes on small and long wavelength (DSSF and DSLF), the surface temperature of the earth (LST), various vegetation parameters (LAI, FVC, fAPAR) and also the radiative power of forest fires (FRP) (Trigo *et al*, 2011). From these basic parameters it is possible to compute the radiative balance which plays a crucial role in the control of soil moisture and evapotranspiration processes, in turn, depending on the type, level and condition of vegetation and photosynthetic activity. Table 1, shows four LSA SAF products linked with forest fires together with a summary of some of the features of the products.

Table 1. LSA SAF products linked with forest fires

	Processing frequency	Product Name	Status	Observation
FD&M	15 Minute	*Fire Detection and Monitoring*	Operational	Identification of pixels with fires in Europe and Africa
RFM	Daily	*Risk of Fire Map*	Operational	Index associated with the forest fire risk in Europe
FRPPixel	15 Minute	*Fire Radiative Power*	Operational	Fire Power in each pixel - MSG resolution
FRP-GRID	Hourly	*Fire Radiative Power – Gridded*	Operational	Fire Power in a 5º resolution grid

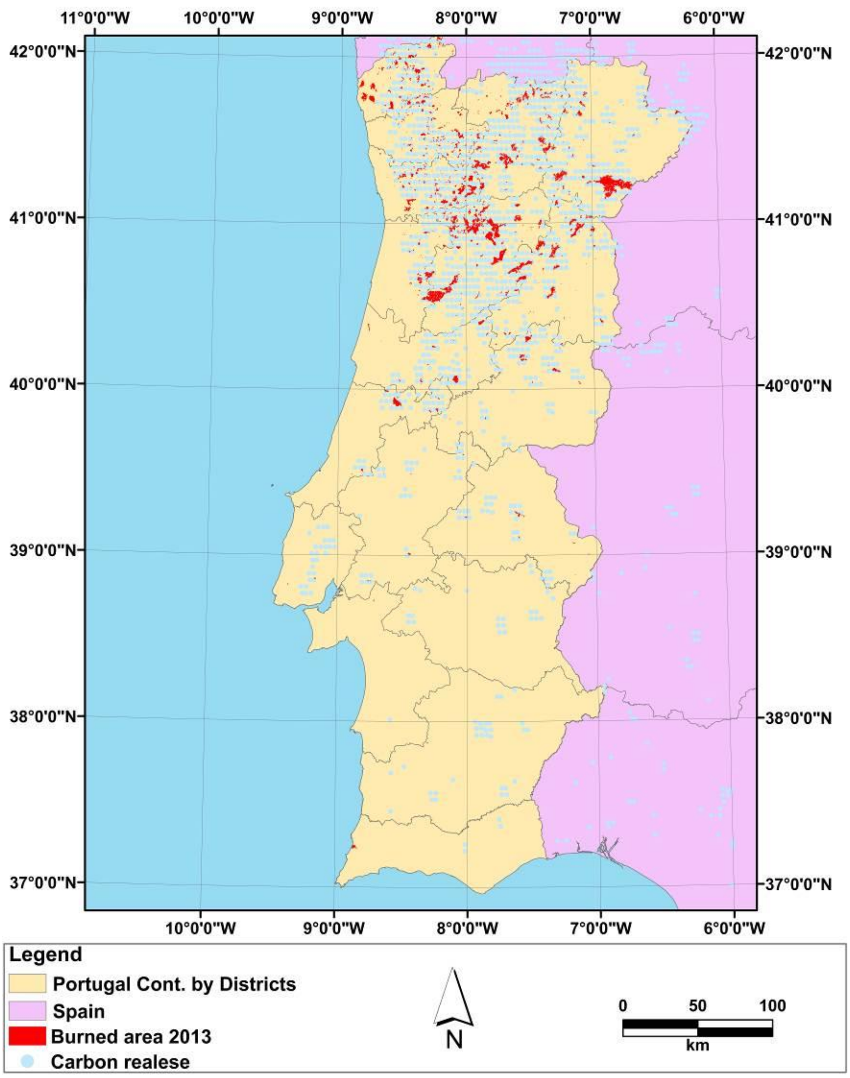


Figure 1 - *Forest fires map to 2013, based on FRP-Pixel LSA SAF product*

SEVIRI (*Spinning Enhanced Visible and Infrared Imager*), is the radiometer on board of MSG satellite systems, with 12 spectral channels each with 3 km spatial resolution (1 km for the high-resolution visible channel) at nadir (Latitude and Longitude are ear 0º, 0º) corresponding, in our latitudes, to a spatial resolution of about 4 km. Temporal revisiting time is of 15 minutes.

Navigation of pixels is possible (associating a Latitude and Longitude to the centre of each *pixels*) and can be used to navigate fire occurrences mapping Carbon or CO_2 over Portugal. Figure 1 shows a fire map for Portugal (January to October 2013): burnt area and CO_2 estimated thorough FRPPixel.

The map was done extracting Portugal mainland from the Europe window of the LSA SAF FRP product distribution. All these products are available for other windows, namely, Europe, Africa (two windows Northern and Southern regions) and South America where this methodology can also be used.

This paper is showing the possibility of monitoring forest fires using FRP product over a region, such as districts, municipalities or other areas of interest, taking advantage of the temporal resolution (15 minutes) of the system. Monitoring specific areas during consecutive days to get information about the evolution of large fires can also be done.

This capability will be illustrated using two large fires: Alfândega da Fé, Picões, (from 8 to 13 July) with 14000 ha of burned area and, in the region of Caramulo (from 21 to 30 August), with 9416 ha according data provide by ICNF (*Instituto de Conservação da Natureza e Florestas*). These 2 large fires where studied in detail by the CEIF (*Centro de Estudos de Incêndios Florestais*) team (Viegas *et al*, 2013).

2. Data and Methodology

Using the *Fire Radiative Power* (FRP), it is possible to estimate the amount of carbon emitted into the atmosphere, due to forest fires. These parameters can be used in various fields of applications, such as mapping fire carbon emissions over the country, allowing strategic decisions to minimize the effects as, for example, reducing health impact.
The FRP estimate the power of wildfires. It is calculated in megawatts (MW) representing the radiant energy, released per unit time, during the forest fire (Wooster *et al*., 2005). The time integration of the FRP during the wildfire lets allows to estimate the total energy released FRE (*Fire Radiative Energy*). The energy released is directly related to combustion and to the rate of fuel consumed process, through a thermal efficiency rate, where carbon is oxidized releasing CO_2. One fraction is emitted as electromagnetic radiation, which can be detected using remote observation (in the case the SEVIRI sensor, installed in the MSG system). The rate of consumption of biomass (TCB), measured in kg/s, is given by the following expression:

$$TCB\ (kg / s) = 0.368\ (\pm 0.015) \bullet FRP\ (MW)$$

Consumption of biomass (CB) estimated in kg, can be calculated from the following expression:

$$CB\ (kg) = 0.368\ (\pm 0.015) \bullet FRE\ (MJ)$$

From the biomass, it is possible to estimate the amount of carbon (C) released into the atmosphere, using a linear statistical approach to estimate the value (in g) for each kg of fuel burned.

$$C\ (g) = 0.47 \bullet CB\ (kg)$$

The statistical value usually used is 0.47. The equivalent amount of CO_2 released into the atmosphere, is approximately four times higher the amount of carbon.
Either, the equivalent amount of CO_2 or the Carbon released into the atmosphere due to forest fires, presents a good fit with the burnt area provided by the Institute of Nature Conservation and Forestry (ICNF) (Bugalho, L. and Pessanha, L., 2011).
IPMA forest fire reports are including, since 2011, a comparison of the full amount (per day) of carbon/CO_2eq released into the atmosphere, and burnt areas (ha), provided by ICNF. Figure 2 represents the CO_2 equivalent released into atmosphere and the burnt area, in 2013 (May to October), for full Portugal mainland.

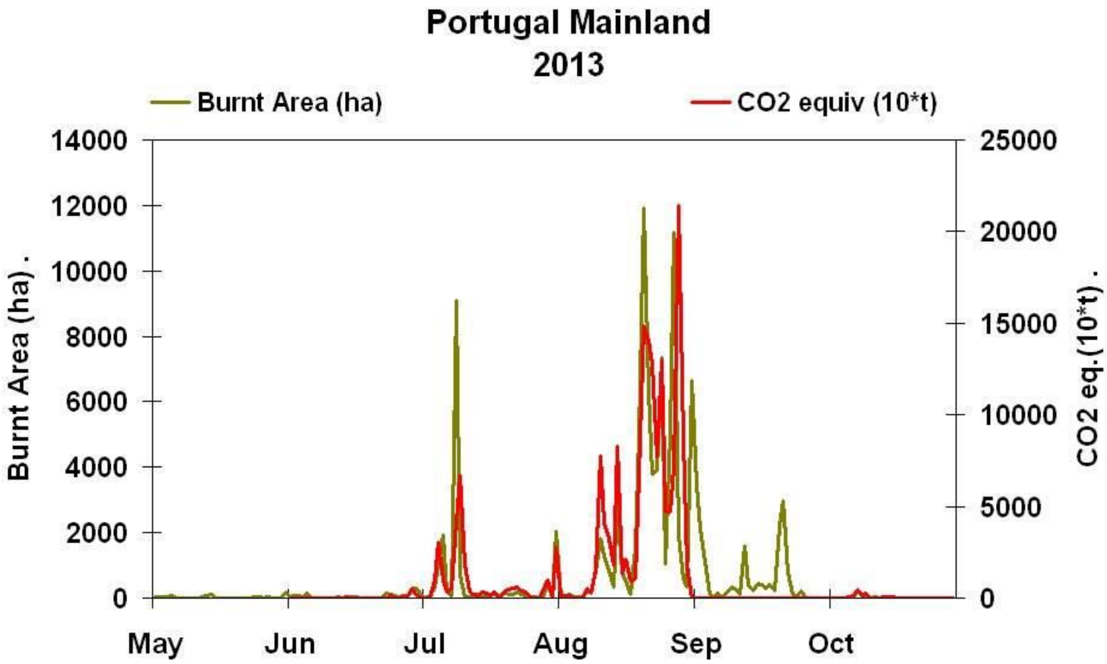


*Figure 2. Daily evolution of the equivalent amount of CO2 released into the atmosphere by forest fires across the country (red, 10*tons), based on FRP and burnt area provided by ICNF updated on November 12/2013 (green, ha)*

LSA SAF FRP is produced and distributed, in NRT (Near Real Time) and off-line, every 15 minutes for all pixels. These data can, subsequently, be used to obtain the Carbon (or equivalent CO_2), estimated for each pixel and integrated for a given area and period of time. Can also to be used to map and monitor forest fires.

This work is showing the possibility of monitoring forest fires, using Carbon computed based on FRP with 4 km of spatial resolution, taking advantage of the temporal resolution (15 minutes) of the system. As test, two major wildfires of 2013 had been used: Alfândega da Fé (Picões), from 8 to 11 July, and another one, in the region of Caramulo, from 21 to 30 August. Burnt area was, respectively, 14000 ha and 9416 ha, according data provide by ICNF.

On July 8th of 2013, at 14:44 h the biggest wildfire register in Portugal in 2013, ignited in the inhabited village of Cilhade, parish of Felgar, municipality of Torre de Moncorvo, district of Bragança, northeast region of Portugal. Few minutes (less than 10 min) after the initial alarm, all the human and material resources available in the region were fighting this wildfire. The combat to fire was difficult by the extreme slope, characterised in this region. On the July 8^{th,} after a few hours of fighting, the fire was dominated and the progression stopped near to Picões in the municipality of Alfândega da Fé (Figure 3), with a burned area relatively small of 180 ha. Despite all the efforts and vigilance strategies of the firelighters of Alfândega da Fé, on July 9th at 14:00 h the fire rekindle and outbreak the perimeter and started a new event with capacity to evolve to a large fire. This wildfire became known as Picões fire, due the location of the rekindle.

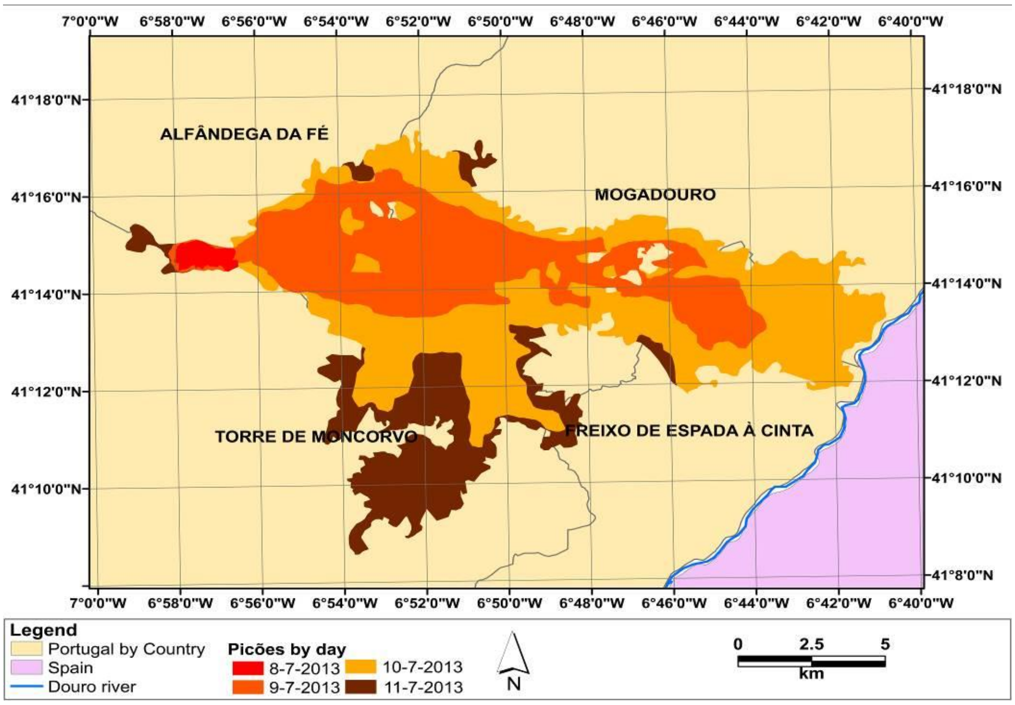


Figure 3. Daily evolution of the burnt area for Alfandega da Fé forest fires

To a better understand of the fire behavior, it is necessary to characterize the region, land use and vegetation, as well as, climate and meteorological aspects.

The geographic characterization of the region from the physical aspect, is continuous mountains with steep slopes and several waterlines running belonging to the basin of the Sabor river.

Land use was mainly occupied for subsistence agriculture, connected to an aged population, olive oil and almond production. *Pinus pinaster* and *Eucalyptus globulus* stands for production of pulp paper.

Meteorologically, the year of 2013 started with large amounts of rainfall. The values of accumulated amounts of precipitation between October 1 of 2012 and June 30 of 2013 were, in general, higher than the normal (average), and ranged from 100% to 150%. The meteorological condition in Portugal mainland, for the initial 10 days of July 2013, according to Novo *et al*, was characterized by an anticyclone system located near to Golf of Biscay, after the 3 of July and again between July 6 and July 10, leading to a very dry and warm air mass, transported from the centre of Spain, resulting in heat wave around the country which last to July 13.

On the July 9th the air temperature record (IPMA meteorological station of Torre de Moncorvo), on the Northeast region of Portugal at 14:00 h (rekindle of the Picões wildfire) attained values over 38ºC, the relative humidity was lower than 13% and the maximum wind velocity was close to 45 km/h. Due the extreme weather conditions the moisture content of fine forest fuels are close to 7%. These conditions were favorable to the development of large fires (slopes, high temperatures, low moisture content of fine forest fuels, strong wind aligned with the drainage basin of the Sabor river).

The wildfire of Caramulo occurred from August 21 to August 30, Figure 4. Most than 20 occurrences were register in these period of time, grouped in three major wildfires, Alcofa (1522 ha of burned area), Silvares (1346 ha of burned area) and Guardão (6548 ha of burned area). These wildfires are the most deadly recording in 2013, reaping the life of four fire-fighters and injuries in several crew members in two human accidents register. Each fire are aggravated by the difficult of the terrain (slope), stands, fuels that provoked embers and burning particles starting often new fire focus and, also, the human limitation to fighting in such conditions.

On August 20th at 23:54 h the Centre of Operations of Tondela firehouse, received an alarm of a wildfire near to the small village of Alcofra. The main cause of this fire was, according to the Portuguese authority, arson.

Reconstruction of these fires was made by the CEIF team, using testimonies of the main interlocutors such as fire-fighters, hotshots, crew members, authority's, civil protection members and local habitants.

The geographic characterization of the region from the physical aspect is continuous mountains with steep slopes. Land use was mainly occupied for subsistence agriculture, connected to an aged population, shrubs, *Pinus pinaster*, *Eucalyptus globulus* stands, and a Forestry Park under the jurisdiction of the National Forestry Service (ICNF).

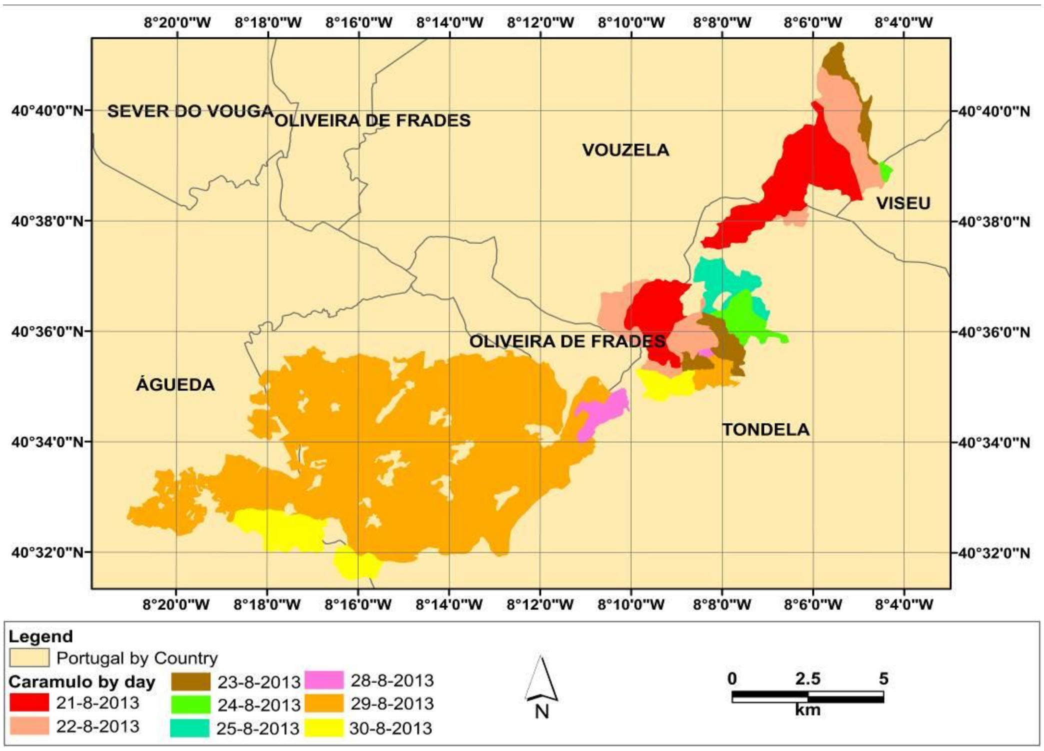


Figure 4. Daily evolution of the burnt area for Caramulo forest fires

The meteorological records shows, from August 21 to August 30, in the station of Viseu, 30ºC of temperature, relative humidity near to 20% and 27 km wind velocity without defined direction, in the first hours of the Alcofa wildfire. The next two days presented same conditions without changes on meteorological conditions. After the August 24, the temperature registered in Viseu oscillated in the range of 10 to 20ºC during the night to around the 30ºC during the day. The wind velocity increased to 50km/h with maximum speed of 60km/h.

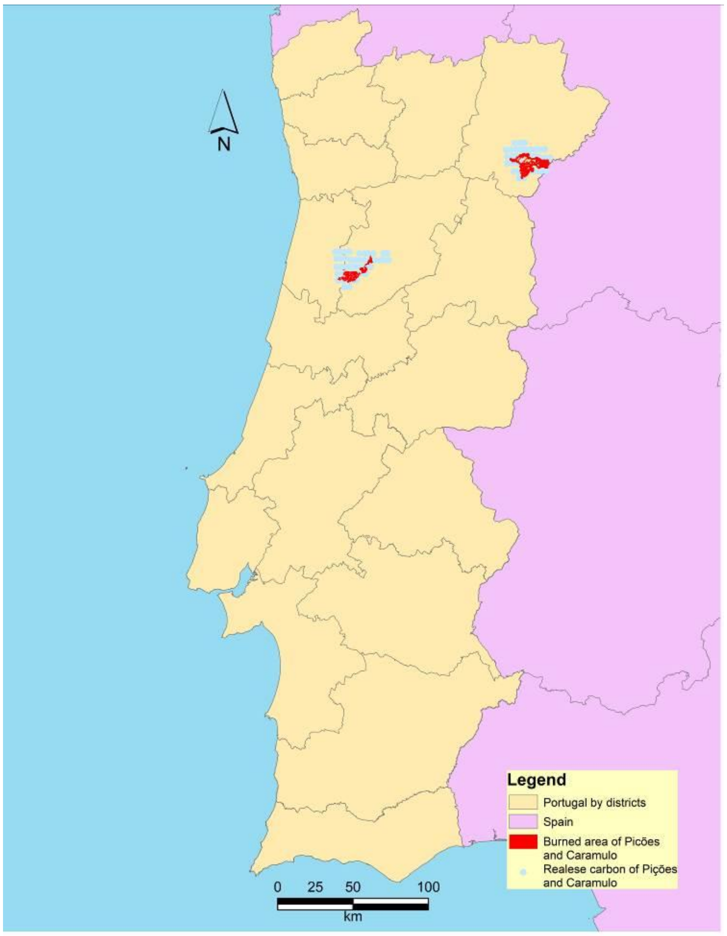


Figure 5 - Localization of two forest fires (Alfandega da Fé and Caramulo). The burnt area measure in red and the FRP product for the same days in blue

Latitude and Longitude of centre of pixels of LSA SAF products are available (geolocation), making possible to map products. For each of the selected wildfire periods already indicated, (8 to 11 July 2013 for Alfandega da Fé and 21 to 31 August 2013 for Caramulo) Carbon data was used to map fires in the correspondent area.

It is possible to observe (Figure) the very good fit of the areas: burnt area prepared by ICNF (*Instituto de Conservação da Natureza e Florestas*) and LSA SAF Carbone map estimated after the integration of the FRP product for the correspondent period of the fires and areas, using all 15 minutes LSA SAF FRP.

Limits for the selection were established:

- Alfândega da Fé: Latitude from 41º 8'N to 41º 18'N, longitude from -6º 59'W to -6º 40'W (Figure 3).
- Caramulo: Latitude from 40º 32'N to 40º 42'N, Longitude from -8º 20'W to -8º 0' W (Figure 4).

3. Results and Discussion

Figure 6 (A and B) shows the evolution of the amount of Carbon released into the atmosphere corresponding to the integrated value (15 minutes), for the each of the two study areas, Alfandega da Fé and Caramulo, for July and August respectively. Analyzing the figures it can be observed a large amount of carbon released into the atmosphere by forest fires from 8 to July 11 in the area of Alfandega da Fé and, on days 21 to 31 August (mainly in 29 and 30), in the Caramulo region.

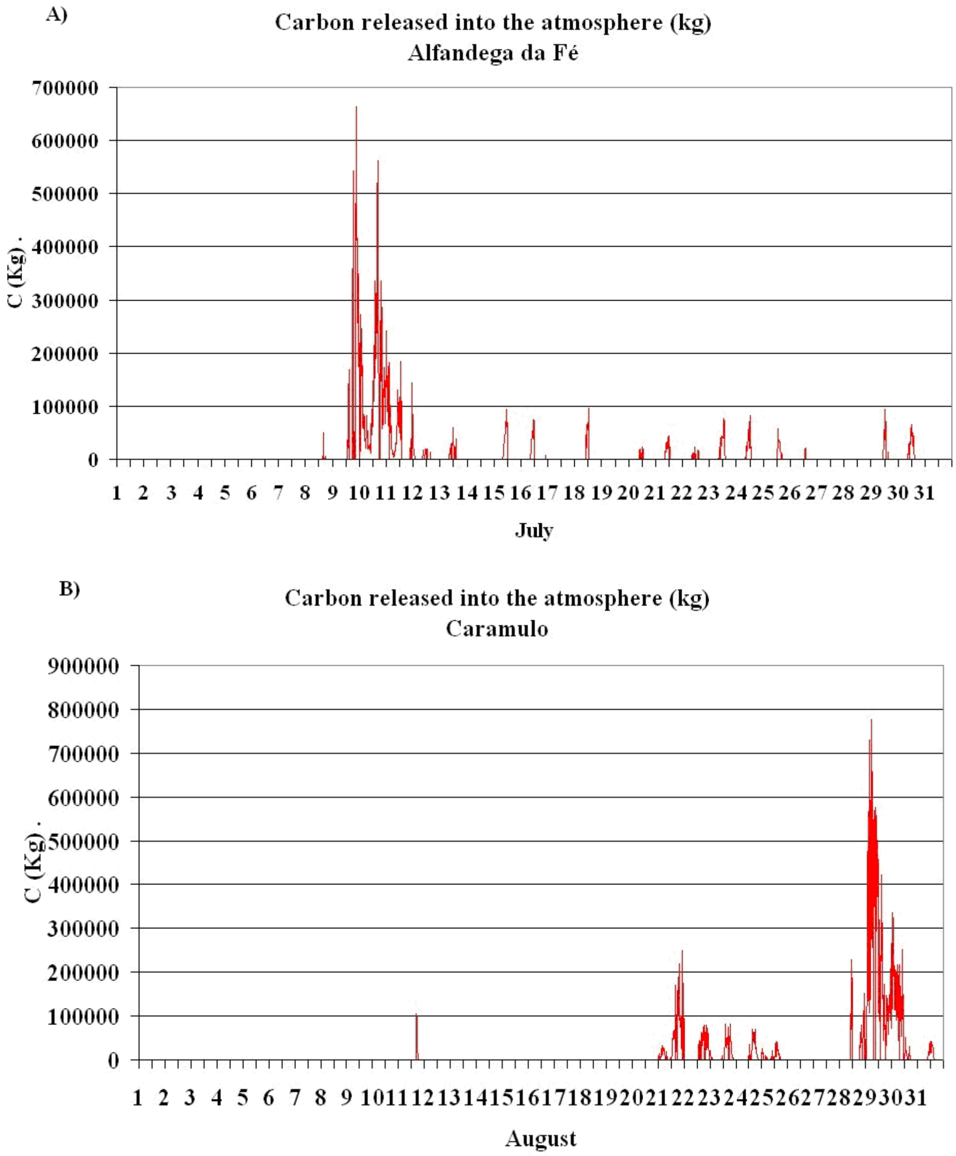
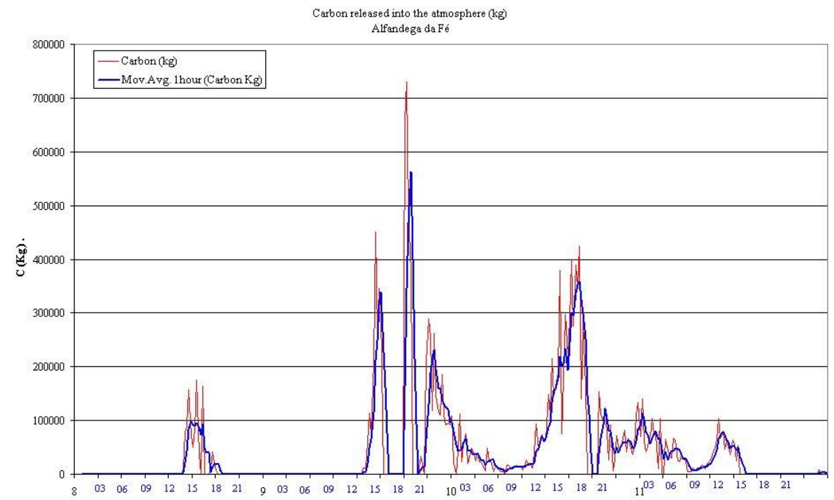
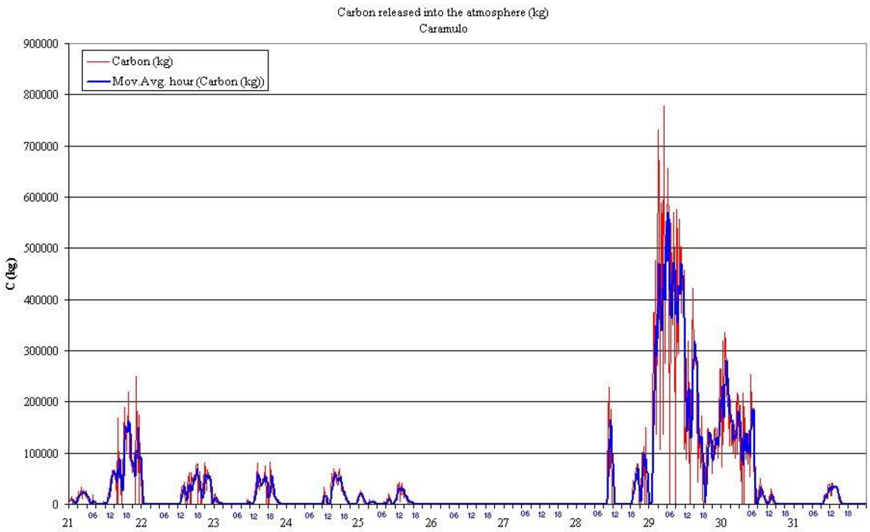


Figure 6 - Daily evolution of the equivalent amount of CO_2 released into the atmosphere by forest fires across the Alfandega da Fé area before defined (A) and Caramulo area before defined (B) (red, tons)

Figure 7 (A and B) shows also the evolution of Carbon released into atmosphere around the periods of maximum emission: Alfandega da Fé (8 to 11 July 2013) and Caramulo (21 to 31 August 2013). A moving average of one hour (in blue) was also included. It is possible to verify that Carbon emission was very high, with a maximum of more than 664 tons of Carbon in 15 minutes, released at 21:00 of 9 July 2013 in Alfandega da Fé and a maximum of more than 777 tons released in 15 minutes on 29 August 2013 at 05:00.



A



B

Figure 7 - The same of Figure 5 during the periods 8 to 11 July and 21 to 31 August, 2013 (red) and moving average of one hour (blue)

The daily evolution of burned areas can be associated to pixels where there are values of Carbone, ie, where it is possible using remote observation, detection of forest fires associated with biomass burning. Figure 8A and B shows the overlay of information about daily evolution of the area burned by forest fires, and pixels. The colour is giving the information about the day of occurrence.

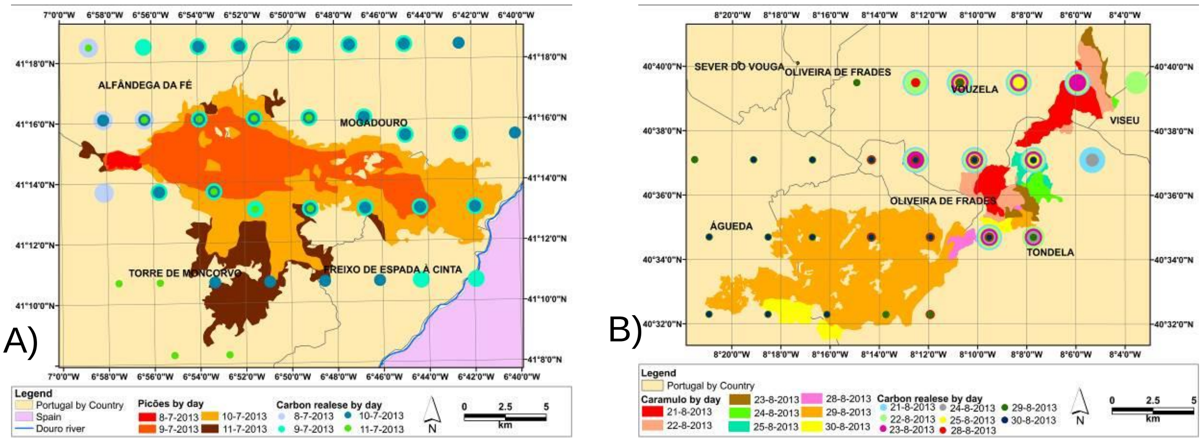


Figure 8- The daily evolution of burnt area for Alfandega da Fé (Picões), (A) and Caramulo (B) and the pixels with FRP values for each day

Note that the location is placed on the centre of the pixel but the fire can be in any place inside of the pixel (or even out the limits of the pixel). Also, geometric correction of the input MSG image can have some impact (geometric corrections done by EUMETSAT) when trying to use in applications near the pixel size. Nevertheless, analyzing Figure 8A and 7B, it is possible to verify that the evolution of spot fires follow the wildfire. For example, in Picões (Alfandega da Fé), Figure 8A, the fire started in further west, on the 8th of July, and it is possible to observe pixels with values of Carbone in light blue in the Figure 8A. On following days (9 and 10), the forest fire migrate to the river eastward. This behaviour is also accompanied by the evolution of Carbone released. On day 11, the wildfire occurs further south, being also accompanied by the Carbone released. Due to the error associated with the pixel size and the geolocation error, associated to remote sensing technique, the pixels with values of Carbone are not always over wildfire.

4. Conclusion

It is possible to conclude that:

- Results obtained so far shows a good correlation between burnt areas and Carbone (or CO_2) released in the atmosphere;
- In the case of the two large fire events in 2013 this is especially true.
- The monitoring Carbon (or CO_2) release in the atmosphere during forest fires, seems good and shall be used as an environmental tool.
- It seems possible to used the estimation of Carbon (or CO_2) released into the atmosphere as an economic way of estimating burned area, with enough quality to be used in NRT (*Near Real Time*).
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