Changes on albedo after a large forest fire in Mediterranean ecosystems

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ABSTRACT

Fires are one of the main causes of environmental alteration in Mediterranean forest ecosystems. Albedo varies and evolves seasonally based on solar illumination. It is greatly influenced by changes on vegetation: vegetation growth, cutting/planting forests or forest fires. This work analyzes albedo variations due to a large forest fire that occurred on 19-21 September 2012 in northwestern Spain. From this area, albedo post-fire images (immediately and 1-year after fire) were generated from Landsat 7 Enhanced Thematic Mapper (ETM+) data. Specifically we considered total shortwave albedo, total-, direct-, and diffuse-visible, and near-infrared albedo. Nine to twelve weeks after fire, 111 field plots were measured (27 unburned plots, 84 burned plots). The relationship between albedo values and thematic class (burned/unburned) was evaluated by one-way analysis of variance. Our results demonstrate that albedo changes were related to burned/unburned variable with statistical significance, indicating the importance of forestry areas as regulators of land surface energy fluxes and revealing the potential of post-fire albedo for assessing burned areas. Future research, however, is needed to evaluate the persistence of albedo changes.

Keywords: albedo, Landsat, burned areas, Mediterranean ecosystems, forest fires,

1. INTRODUCTION

Forest fires are an annually recurring phenomenon in Mediterranean countries, with an average of 55,500 fires per year in the period 2006-2010[1]. They have important management and research implications spanning a wide range of scientific disciplines[2]. Traditionally burned areas were mapped by field work, although at present satellite data sensors are widely used to map the extent of affected areas. Numerous remote sensing-based studies[3,4,5,6,7] have sought to determine the extent of burned area and the long-term effects of fires on ecosystem health.

Moderate to high spatial resolution satellite data, such as provided by Landsat, give the opportunity for detailed spatial mapping of burned areas. Especially, since 2008 when the United States Geological Survey (USGS) started to distribute Landsat data at no charge via the Internet. This provided the opportunity to consider Landsat data for long-term, large area, burned area monitoring[6]. In this frame, it is worth mentioning the U.S. Monitoring Trends in Burn Severity (MTBS) project that is producing annual Landsat derived maps of burned areas and burn severity levels for all the conterminous U.S. and Alaska[8].

Albedo varies spatially and evolves seasonally based on solar illumination changes, vegetation growth, and human activities such as cutting/planting forests and slash-and-burn agricultural practices[9]. Wildfires can significantly alter albedo by changing the amount of solar radiation absorbed in the climate system[10]. The main post-fire changes in albedo are associated with dissipation of charcoal and ash, and vegetation regrowth. Immediately after a fire event, vegetation loss and surface blackening causes an albedo decrease[11,12]. The long-term effects of biomass burned on albedo can be related to the secondary succession process of forest replacement by croplands and grasslands that have higher albedo[13].

Most studies relating wildfires and albedo have been done in boreal forests[14,15] and/or using data from the Moderate

Resolution Imaging Spectroradiometer (MODIS). However, albedo change caused by fires varies by ecosystem type[13]. The aim of this study is to analyze the relation between surface after fire and albedo in Mediterranean forest ecosystems (immediately after fire and a summer after fire). To our knowledge, though we found some work relating albedo to burn severity in Mediterranean ecosystems (see [16]), this is the first study that propose albedo as a potential indicator of surface burned by a wildfire using Landsat Enhanced Thematic Mapper (ETM+) data and ground measurements.

2. MATERIAL

2.1 Study area

The study site, 'Castrocontrigo', is located in the Sierra del Teleno, in northwestern Spain (Figure 1). It is a small mountain range with an average slope of 10% and elevation ranges above sea level between 850 to 2,100 m. The climate is Mediterranean with an average annual rainfall between 650 and 900 mm and two- three months of dryness in the summer. Soil in this area is very sandy and acidic (pH=5.5) with low organic matter content[17]. The Third Spanish National Forest Inventory shows that within the fire scar roughly 73% was covered by *Pinus pinaster* Ait., 3% by *Pinus nigra* Arm., 2% by *Pinus sylvestris* L., 7% by *Quercus ilex* L., 5% by *Quercus pyrenaica* Willd and 10% by shrubs (*Erica australis* L., *Calluna vulgaris* (L.) Hull, *Chamaespartium tridentatum* (L.) P.E. Gibbs, *Halimium alyssoides* Lam and *Genista florida* L.).
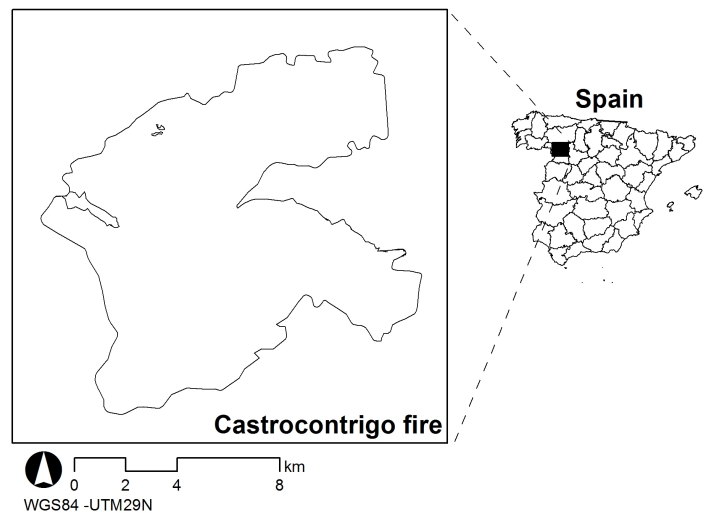

Figure 1. Study area location.

Fires have frequently occurred in this forest ecosystem, generally affecting small areas and mostly caused by dry spring-summer storms. However, in August 2012 there was a large fire, which burned 117.75 km^2 for three days (between August 19-21, when a heat wave affected the study site). The 2012 spring was drier than usual and the summer was extremely dry (it was the second driest summer in the last 60 years) with an average August precipitation 40% less than the average value. On the contrary, the fall of 2012 was very humid (40% more than usual). Regarding the initial fire weather conditions, the fire had a Haines Index equal to 6 (maximum value), which shows the high potential contribution of dry, unstable air to the development of the large and erratic plume-dominated fire. Due to the importance of this fire, it was recorded in the Reference Report by the Joint Research Centre of the European Commission: "Forest Fires in Europe, the Middle East and North Africa 2012", as one of the most important large fires at the European level[1].

2.2 Datasets

We used as post-fire data two Landsat 7 Enhanced Thematic Mapper (ETM+) scenes (path/row 203/31), acquired respectively on September 6, 2012, and September 9, 2013, and downloaded from the USGS. We tried to minimize the changes on illumination conditions and their influence on albedo by choosing approximately the same date of acquisition. Fortunately, the forest fire was located in the middle of the Landsat-7 ETM+ scenes and we did not locate any field plot in the affected area by the Scan Line Corrector (SCL) failure.

We ground measured the thematic variable burned/unburned in 111 field circular-plots (30m diameter) nine to twelve weeks after fire (27 unburned plots, 84 burned plots).

A digital elevation model (DEM) was used to perform the topographic normalization of the Landsat 7 ETM+ images. We utilized the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model Version 2 (GDEM V2) provided by USGS.

3. METHOD

As showed in Figure 2, firstly the Landsat 7 ETM+ scenes were windowed to the forest fire (latitude / longitude coordinates: upper left corner, 42º20'38.27''N / 6º16'49.51''W; and lower right corner 42º13'59.97N / 6º8'28, 40''W). The subset images were topographically normalized and atmospherically corrected using the C-correction algorithm[18]. The reflective bands were scaled to surface reflectance by using the image-based cosine of the solar transmittance (COST) method[19].
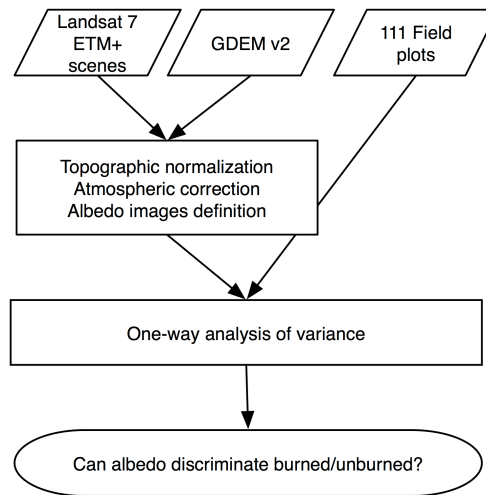

Figure 2. Flowchart methodology.

Next, we used the algorithms to narrowband to broadband conversion of albedo[20,21] (see equations 1-7). The validation results indicated an excellent agreement between the predictions by these formulae and ground measurements. The average residual error (RSE) of predicted broadband albedos for most sensors including ETM+ was about 0.02.

$$\alpha_{short} = 0.356\alpha_1 + 0.130\alpha_3 + 0.373\alpha_4 + 0.085\alpha_5 + 0.072\alpha_7 - 0.0018 \tag{1}$$

$$\alpha_{vis} = 0.443\alpha_1 + 0.317_2 + 0.240\alpha_3 \tag{2}$$

$$\alpha_{vis\_diffuse} = 0.556\alpha_1 + 0.281\alpha_2 + 0.163\alpha_3 - 0.0014 \tag{3}$$

$$\alpha_{vis\_direct} = 0.390\alpha_1 + 0.337_2 + 0.274\alpha_3 \tag{4}$$

$$\alpha_{NIR} = 0.693\alpha_4 + 0.212\alpha_5 + 0.116\alpha_7 - 0.003 \tag{5}$$

$$\alpha_{NIR\_diffuse} = 0.864\alpha_4 + 0.158\alpha_7 - 0.0043 \tag{6}$$

$$\alpha_{NIR\_direct} = 0.659\alpha_4 + 0.342\alpha_5 - 0.0033 \tag{7}$$

where: α_{short} represents the albedo in the shortwave lengthwaves, α_{vis} the albedo in the visible lengthwaves, α_{NIR} the albedo in the near-infrared (NIR) lengthwaves, and α_i indicates the albedo in the 'i' Landsat ETM+ band.

Finally, we applied a mean 3x3 filter to the albedo images, and extracted the digital values for the field plots surveyed. We used one-way analysis of variance (ANOVA) to check if post-fire albedo allows us to differentiate with statistical significance burned from unburned class.

4. RESULTS AND DISCUSSION

Figure 3 displays the immediately post-fire albedo (shortwave, visible and NIR). From it, we visually notice important differences between burned and unburned areas. Additionally, spatial differences inside of burn perimeter can be visually observed mainly in α_{NIR}.
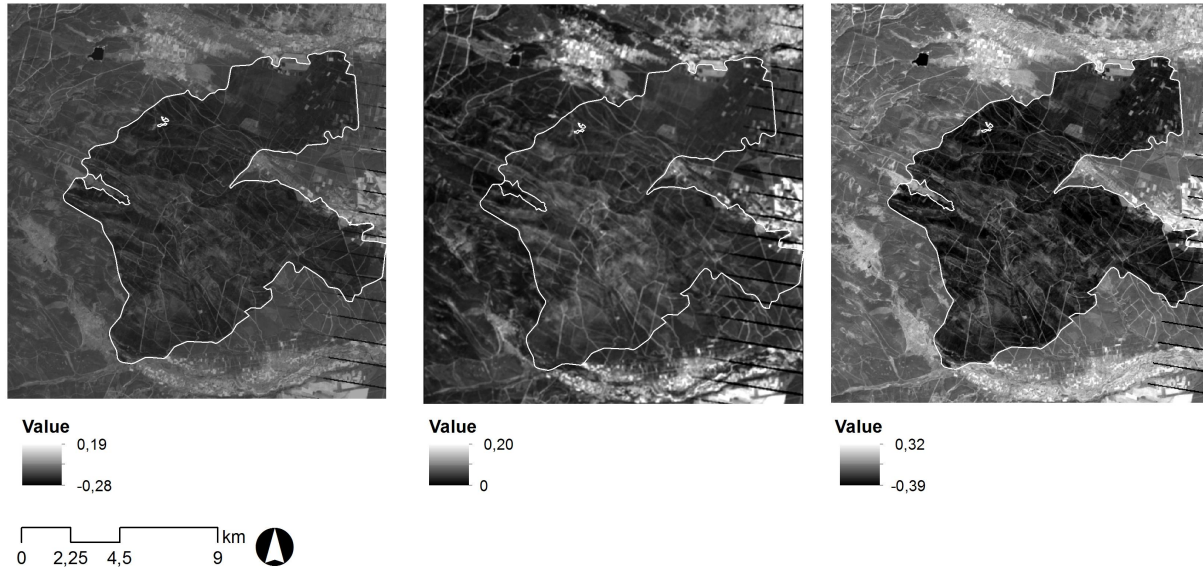

Figure 3. Immediately post-fire albedo: left, shortwave, center, visible, right, near-infrared.

The results of one-way analysis of variance applied to the two post-fire Landsat 7 ETM+ images, September 6, 2012, and September 9, 2013 are shown in Table 1. When considering the immediately after fire image, we observed significant differences (p-value<0.01) between the mean albedo value in unburned and burned plots for all considered spectral range (shortwave, visible, and NIR). A year after fire significant differences between burned and unburned values were observed for all albedo images except for $\alpha_{NIR\_diffuse}$, that confused unburned and burned classes (p-value = 0.8424). We also observed a decrease of the immediately after fire albedo in shortwave and NIR spectral regions (from 0.1041 to 0.0842, and from 0.1656 to 0.1068) and a little increase of the visible albedo (from 0.0458 to 0.0538). A year after fire albedo increased over its pre-fire values in every considered spectral region (0.1060 vs. 0.1342, 0.0365 vs. 0.0742, and 0.1761 vs. 0.1993).

Table 1. One-way analysis of variance checking whether there are significant differences between the mean albedo value in unburned and burned area.

Classes	α_{short}		α_{vis}		$\alpha_{vis\ diffuse}$		$\alpha_{vis\ direct}$		α_{NIR}		$\alpha_{NIR\ diffuse}$		$\alpha_{NIR\ direct}$	
	μ	p-value	μ	p-value	μ	p-value	μ	p-value	μ	p-value	μ	p-value	μ	p-value
Landsat 7 ETM+. September 6. 2012														
Unburned	0.1041	0.0000	0.0458	0.0048	0.0409	0.0018	0.0475	0.0073	0.1633	0.0000	0.1656	0.0000	0.1645	0.0000
Burned	0.0842		0.0538		0.0493		0.0553		0.1163		0.1068		0.1138	
Landsat 7 ETM+. September 9. 2013														
Unburned	0.1060	0.0000	0.0365	0.0000	0.0314	0.0000	0.0383	0.0000	0.1761	0.0008	0.1823	0.8424	0.1772	0.0007
Burned	0.1342		0.0742		0.0669		0.0770		0.1993		0.1836		0.2014	

μ: mean value

Immediately after fire, the albedo suffered a decrease of approximately 20% in shortwave lenghtwaves and 30% in NIR (Table 2). The visible albedo increased its pre-fire (unburned) values in about 20%. A year after fire, the albedo increased its pre-fire values (unburned plots) in approximately 26% (shortwave), 105% (visible) and 13% NIR. Our results agree with other researchers' findings. On Mediterranean ecosystems. an immediate post-fire shortwave albedo

decrease was observed after the large fires that burned the Peloponnese peninsula (Greece) in the 2007 summer[16]. This effect had a relatively short duration, as during the first post-fire winter period, which is a period of heavy rainfall in the Mediterranean, most of the char materials were removed by fluvial and aeolian forces. The combination of char removal and regenerating species caused an increase during the next post-fire summer period. The same trend on albedo change was found in a study about albedo and surface temperature evolution after fire[22]. Summer albedo also increases above pre-fire levels because early successional plant functional types, including grasses and deciduous trees and shrubs, have leaves and branches with higher albedo than those of evergreen needle-leaf trees[23,24,25].

Table 2. Difference between unburned and burned mean albedo values.

Albedo	$\mu_{unburned} - \mu_{burned}$ immediately after fire September 6. 2012		$\mu_{unburned} - \mu_{burned}$ a year after fire September 9. 2013	
	absolute	relative (%)	absolute	relative (%)
α_{short}	0.0199	19.12	-0.0282	-26.6
α_{vis}	-0.0080	-17.47	-0.0377	-103,29
$\alpha_{vis\_diffuse}$	-0.0084	-20.54	-0.0355	-113.06
α_{vis_direct}	-0.0078	-16,42	-0.0387	-101.04
α_{NIR}	0.0470	28.78	-0.0232	-13.17
$\alpha_{NIR\_diffuse}$	0.5880	35.51	-0.0013	-0.71
α_{NIR_direct}	0.0507	30.82	-0.0242	-13.66

$\mu_{unburned}$: mean albedo value in unburned plots; $\mu_{unburned}$: mean albedo value in burned plots;

In boreal forest ecosystems, during the first year after fire, summer albedo (shortwave and NIR) decreased substantially below pre-fire levels. In addition, visible albedo remained relatively constant or even increased[14]. Post-fire summer albedo is typically reduced for several years as a consequence of black carbon coatings on soils and the boles of dead trees[26]. The establishment and growth of herbaceous plants, shrubs, and deciduous trees caused rapid increases in summer albedo within the first decade after fire[12,24].

5. CONCLUSION

We evaluated the changes in albedo due to fire in Mediterranean forest ecosystems, considering as study area a large forest fire in north-western Spain. The vegetation state (burned or unburned) was measured in 111 field plots. One-way ANOVA between ground measured vegetation state and albedo (short, visible and NIR), both immediately after fire and a year after fire, showed that burned areas had an albedo value statistically different from unburned areas (with the exception of $\alpha_{NIR\_diffuse}$ a year after fire). Immediately post-fire albedo (short and NIR) decrease its value whereas visible albedo increased it. A year after fire albedo increased its value for all considered spectral ranges. These results demonstrate the potential of albedo for assessing burned area in Mediterranean ecosystems. Its performance should be, however, evaluated in other fire regimes and vegetation types.

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