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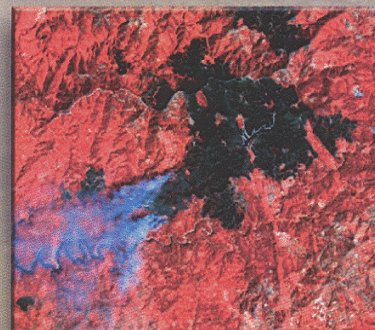
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PROCEEDINGS OF THE 6TH INTERNATIONAL WORKSHOP OF THE EARSeL SPECIAL INTEREST GROUP ON FOREST FIRES ADVANCES IN REMOTE SENSING AND GIS APPLICATIONS IN FOREST FIRE MANAGEMENT TOWARDS AN OPERATIONAL USE OF REMOTE SENSING IN FOREST FIRE MANAGEMENT

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The mission of the Institute for Environment and Sustainability is to provide scientific-technical support to the European Union's Policies for the protection and sustainable development of the European and global environment.

An operational protocol for post-fire evaluation at landscape scale in an object-oriented environment

M.F. Álvarez
University of León, Avda. Astorga sn 24400, Ponferrada (León), Spain, flor.alvarez@unileon.es

J.R. Rodríguez
University of León, Avda. Astorga sn 24400, Ponferrada (León), Spain, jr.rodriguez@unileon.es

D. Vega-Nieva
University of Vigo, Campus As Lagoas, Pontevedra, Spain, danieljvn@gmail.com

F. Castedo-Dorado
University of León, Avda. Astorga sn 24400, Ponferrada (León), Spain, fcasd@unileon.es

ABSTRACT: Post-fire effect assessment and mapping in a very fragmented and diverse landscape is crucial to prioritize management actions, mainly when fires are very numerous and disperse. The processing protocol should be affordable and operational, in order to be applied when management decisions were required by the administration. The consistency and quality of the results is linked to the image processing stages to address image radiometry, normalization, and computation of the spectral indices. Computation errors, disk storage needs, and processing time required diminished when image processing steps were algebraically combined, so that the sequential integrated data processing protocol operates in memory and produces only the desired final outputs, and it can be easily repeated. The individual elements of the algorithm (raw Landsat 5 TM imagery, calibrated data, top-of-atmosphere reflectance, spectral indices) are described, as well as the protocol resulting of its combination. In this communication the processing protocol is utilized to map burns and post-fire effects in NW Spain. The resulting spectral indices were used as inputs in a new process, consisting on applying a non-parametric thresholding method to spectrally homogeneous objects. Thresholds were calibrated and validated using field data, gathered according to a protocol developed in coordination with the main fire research station in NW Spain. Validation of burn area classification using a random sample of 200 burn perimeters identified on the imagery showed 100% agreement with the results of the automatic classification, by using the dNDVI and NIRpostfire. If NIRpostfire was not used commission error increased significantly (at $p > 0.001$). The validation of the post-fire effect classification showed 100% agreement for moderate and high burn severity (post-fire effects), and 66% accuracy for the low class. Omission errors in the latter class are not very important in this environment, because those areas are not a priority for managers. Advantages of using an object-oriented approach instead of a pixel-based classification were demonstrated. Computing times for preprocessing decreased 50% using the IDL protocol, compared to the traditional approach. The adapted version of this protocol is therefore available to be used for detecting, mapping and classifying burn areas, so that 17 days are required to achieved the classifications and maps if one person is doing it. As a result, burns were mapped according to three post-fire effect levels, in agreement to the Ministry of Forestry request for a functional tool for decision making

1 INTRODUCTION

Post-fire effect assessment and mapping is a useful tool from two points of view: (i) for post-fire planning, because it minimizes field work in restoration plans (Diaz Delgado, 2000; Chafer et al., 2004), and (ii) as information source for probabilistic models for fire simulation by using the existing relationships between post-fire effects and environmental parameters (Kushla and Ripple, 1997). Post-fire planning is crucial in areas with frequent precipitations, which require identifying and characterizing the scenario derived of precipitations rapidly, due to the possibility of suffering runoff phenomena. Although it is known that erosion is a consequence of post-fire precipitations, there are not many studies about how areas with different burn severity react to precipitations or how soils react regarding water repellence when different severities are considered (Shakesby et al. 2003; Chafer et al., 2004; Lewis et al., 2004). Zoning regarding post-fire intervention priority in Spain has been tackled in several studies (Díaz-Delgado, 2000; Navarro et al., 2001; Ruiz-Gallardo et al., 2004) by using post-fire effect mapping based on medium spatial resolution remote sensing imagery and achieving classification accuracies higher that 75%. Nevertheless the inconsistent use of fire descriptors (fire intensity, fire severity, burn severity) confuses measurement and interpretation of field and remote sensed fire effects. Lentile et al. (2006) recommend that processes associated with fire intensity and severity be evaluated in terms of either active fire characteristics or post fire effects. Therefore, post-fire effects would involve all measurements

acquired after the fire has passed (e.g. soil charring, nutrient changes, surface spectral changes, vegetation response). Usually post-fire effects have been identified with burn severity, a term which incorporates both short- and long-term post-fire effects on the local and regional environment (Lentile et al, 2006), and it is defined by the degree to which an ecosystem has changed owing to the fire (De Bano et al., 1998; Ryan, 2002; Neary et al., 2005). Traditionally burn severity has been determined by field work (Pérez and Moreno, 1998), but this approach is not operational due to its cost and its lack of spatial representation, while by using remote sensing imagery a detailed coverage is affordably achieved (Wulder and Franklin, 2003). At landscape scale, remote sensing, GIS and a minimum amount of field work allow determining post-fire effects, as input for post-fire planning, although some limitations have been found (Miller et al., 2003; Roy et al., 2006). Extended reviews of approaches with different statistical methods and imagery are available at Rogan and Franklin (2001), Parra and Chuvieco (2005), Key and Benson (2006) and Lentile et al. (2006). At the landscape scale, Landsat 5 TM or Landsat 7 ETM+ data, in particular when processed using change detection approaches, has successfully been applied in a number of studies to detect and map post-fire effects, due to their adequate spatial/spectral resolution at landscape scale (Chuvieco et al., 2006). Prominent among the approaches identified as having operational potential is the use of the NDVI (Normalized Difference Vegetation Index) (Díaz-Delgado and Pons, 1999; Rogan and Franklin, 2001; Ruiz-Gallardo et al., 2004; Hammill and Badstock, 2006;) and NBR (Normalized Burn Ratio) (White et al., 1996; Cocke et al., 2005; Epting et al., 2005; Key and Benson, 2006) which have been shown to capture forest changes due to fire. Both NDVI and NBR can be used in a single date approach or a temporal (multidate) change detection approach (Lentile et al., 2006), by computing dNDVI and dNBR (post-fire value – prefire value). For the successful application of this method, both input Landsat images need to be processed using a series of radiometric corrections and normalizations that reduce the spectral variations that may be related to different sensor characteristics, atmospheric conditions, and viewing and illuminating geometries. These processing steps are applied to each pixel of the input images. Han et al. (2007) developed an approach for combining processing steps (image radiometry, normalization, and computation of the spectral indices) to facilitate a more streamlined and computationally efficient approach to change detection using Landsat 5 and Landsat 7 for mountain pine beetle attack detection. The proposed approach mitigates opportunities for inappropriate scaling between processing steps, the consistency of which is especially important for threshold based change detection procedures. In addition, savings in both processing time and disk storage are afforded through the combination of processing steps, resulting in savings of 50% and 69% in computing times and disk space requirements respectively. This tested protocol has resulted to be useful for users of remote sensing products, focused on the results of change analyses and the final product, rather than on the processing steps (Han et al., 2007).Taking into account the requirements of post-fire effect assessment and the complexity change detection when dealing with large scenes from different dates and areas, the following objectives are addressed: (i) to adapt the integrated approach for Landsat data radiometric correction and normalization proposed by Han et al. (2007) to a post-fire effect environment, (ii) to develop an operational protocol to achieve useful remote sensing outputs regarding burn severity (post-fire effects), so that it can be repeated and compared at anytime it is required and which takes into account environmental researcher/manager requirements (for hydrologic restoration, vegetation rehabilitation), in order to be applied when management decisions were required by the administration. Moreover, two final products were aimed in this work: (i) delimitation of burn areas and its classification regarding post-fire effects, and (ii) that this information could be available rapidly by the forest administration in order to be considered in post-fire planning.

2 MATHERIAL AND METHODS

2.1 *Imagery and cartographic data*

Demonstration of the proposed technique is over Galicia, located in the NW of Spain. This area of 29500 km^2 was devastated partially by forest wildfires in 2006, mainly in August. Forests occupy 60% of this area, and are dominated by *Eucalyptus globulus, Pinus radiata* and *Pinus pinaster*. Four Landsat 5 TM scenes acquired on two dates were selected for analysis: June 1, 2006 as pre-fire data, and September 5, 2006 as post-fire data. Although each pair of scenes (path 204, rows 30 and 31) were sequentially collected on the same date, mosaicking was not undertaken until the radiometric corrections were performed, to create a seamless image for each date (June 1, 2006 and September 5, 2006). Cartographic vector data scale 1:25.000 and a digital terrain model (50 m grid size) provided by the administration were required for geometric correction. They were both referred to European Datum 1950 (ED50) and projected to UTM Zone 29T.

2.2 *Field data*

Field data were required to validate the results, regarding burn area assessment and mapping, as well as for post-fire effects (burn severity). Perimeters of 8 areas burnt in August 2006 were provided by the administration in raster format, so that they were digitalized into vector and referred to ED50 (UTM Zone 29T projection). Ten additional field plots were settled to evaluate post-fire effects regarding, soil, understory and trees, adapting the FIREMON (Fire Effects Monitoring and Inventory Protocol) (Key and Benson, 2003) to the forest conditions of the study area (Galicia). One advantage of this method is that it provides a quantitative value of severity by calculating the Composite Burn Index (CBI) proposed by Key and Benson (2006), which has been related to spectral indices derived from remote sensed imagery (e.g. NBR). The protocol was developed in coordination with CIF Lourizán, the main fire Research Station in NW Spain, which dealt with the field work and adapted the FIREMON, so that B, C, D original FIREMON strata were merged into one. Therefore the following three strata were defined to evaluate post-fire effects (burn severity): (1) substrate: litter, light fuel, superficial mineral soil, (2) understory: shrubs, subcanopy, (3) upper forest canopy, dominant trees. In addition, modifications for post-fire effects on substrate and forest canopy monitoring were proposed, and a visual key was also developed to complete the descriptive information for quantifying post-fire effects in each sample as low, moderate and high (burn severity) (Figure 1).

Figure 1. Low, moderate, and high post-fire effects in Galicia (NW Spain) (from right to left). Classified via consistent visual assessment of ground, understory and canopy fire effects, according to the protocol adapted by CIF Lourizán using FIREMON as reference.

LOW   MODERATE   HIGH

Therefore, each severity level resulted in the following characteristics, considering effects in soil, understory and canopy (Table 1).

Post-fire effect class	Effect on the strata		
	Soil	Understory	Canopy cover
Low	Duff and litter affected by scorch. Mot exposed mineral soil	Shrub affected by scorch. Incomplete consumption of ferns.	Green crowns or occasionally scorched. Scorch height less than 2 m.
Moderate	Presence of duff affected by scorch. Less than 50% of the surface area showing exposed mineral soil.	Shrub retains the outer fine branching. Ferns have only the central stalk	Crowns that retain scorched leaves. Scorched height between than 4 and 7 m.
High	Exposed mineral soil, which can loose soil structure because of the consumption of the organic matter. Frequent presence of heating points.	Shrub only maintains the stump or the outer thick branching. Complete consumption of ferns.	Total consumption of the crown. Scorched height greater than 7 m or the whole tree.

2.3 *Remote sensing approach: indices selection, preprocessing, classification and validation*

Burn area and post-fire effect detection and mapping were performed by using the dNDVI and dNBR indices. As the dNDVI and the dNBR are calculated based on the spectral indices derived from two input images, any variations between the inputs that are not indicative of actual changes in land cover should be minimized prior to their computation. Sources of such variations include different sensor characteristics, atmospheric conditions, and view and illumination geometries. A series of processing steps is proposed to reduce these possible sources of variation. The processing steps comprise top-of-atmosphere (TOA) radiance correction, TOA-reflectance correction, and normalization. The TOA-radiance and reflectance corrections are employed for atmospheric correction when *in-situ* measurements of atmospheric and climate conditions at the time of image acquisition are unknown and the imagery was acquired under clear-sky conditions. Using the gain and offset derived from dark and bright targets, the normalization is conducted to reduce image discrepancies possibly remaining from differing illumination geometries of the input imagery that were not fully addressed by the TOA-corrections. All this steps were semi-automatized in two IDL (ENVI scripts). Co-registration between images was performed, but not a geometric correction, in order to preserve original reflectance values as much as possible, so that orthorectification was performed on the final classification, not on the raw imagery.

After imagery preprocessing and indices computation (as well as image differencing), imagery was segmented using a scale parameter of 10 (Alvarez, 2006) and bands TM 3, 4, 7 (post-fire image) and dNDVI (software eCognition 5.0). Burn area detection and mapping were performed using the dNDVI ($NDVI_{post-fire}$- $NDVI_{pre-fire}$) and $NIR_{postfire}$ (Band TM 4 in the post-fire image) values. Segments were classified in an object oriented approach, so that thresholding values were settled considering several burn areas identified visually on the image by using adequate band combinations. $NIR_{postfire}$ was necessary to avoid misclassifications due to phenological differences in agricultural areas. Burn areas were later classified according to the three post-fire effects defined in Table 1 and Figure 1, by using the dNBR ($NBR_{post-fire}$- $NBR_{pre-fire}$) and $NBR_{postfire}$ values. Burn perimeters were validated using field data and visual tests on the images. Post-fire effect classification was validated with the field sample of 10 plots described above. Prior to calculating perimeters, areas and mapping, results were orthorectified using ERDAS Imagine and cartographic and MDT data described above. Afterwards a calendar identifying the critical steps of the process was developed, in order to help managers to decide whether the method is useful and operational for their rehabilitation interests.

3 RESULTS AND DISCUSSION

Validation of burn area classification using a random sample of 200 burn perimeters identified on the imagery showed 100% agreement with the results of the automatic classification, by using the dNDVI and NIRpostfire. If NIRpostfire was not used commission error increased significantly (at p>0.001). If imagery from August or late July were available as pre-fire data source, phonological differences would be not so important and the NIR might be not so crucial, as reported in studies which only considered dNDVI (Ruiz-Gallardo et al., 2004; Hammill and Badstock, 2006; Díaz-Delgado and Pons, 1999; Rogan and Franklin, 2001).

The validation of the post-fire effect classification showed 100% agreement for moderate and high burn severity (post-fire effects), and 66% accuracy for the low class. Omission errors in the latter class are not very important in this environment, because those areas are not a priority for managers. Using NBRpostfire involves considering not only changes and differences, but also the site final post-fire appearance. Therefore, priority areas to be restored were identified taking into account that in some areas the change might not be very large, but because the original conditions (previous to fire) were adverse, after the fire are critical for runoff and require a rapid intervention. Similar results were achieved using this index (White et al., 1996; Cocke et al., 2005; Epting et al., 2005; Key and Benson, 2006), reporting accuracies between 70-85%, in different environments and at landscape scale. For both burn area identification and classification, specific thresholds had to be settled for the study area, and general values from references were not suitable for Galicia.

The object-oriented approach performed was compared to a pixel-based one, and results for burn area mapping were significantly better (p>0.001) using segments (objects), mainly regarding burn area delineation and the absence of isolated misclassified pixels. This result agrees with the conclusions of Alvarez (2006) for forest cover classification using Landsat 5 TM imagery in a similar study area in Galicia, which recommended using an object oriented approach to avoid the misclassification due to fragmentation.

Computing times for preprocessing decreased 50% using the IDL protocol, compared to the traditional approach, similar to the values reported by Han et al. (2007). The adapted version of this protocol is therefore available to be used for detecting, mapping and classifying burn areas. Therefore a chronogram was presented to reflect the processes and timing required to repeat this analysis at anytime required (Table 2); it showed that 17 days are required to achieved the classifications and maps if one person is doing it. The critical steps are data acquisition (availability and ESA quality control) and field work for validation (it depends on weather conditions). This validation is not necessary (the method is already validated), but advisable.

Figure 2. Chronogram with processes and timing required to repeat this analysis.

TASK	DAY	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Imagery acquisition		■	■	■	■	■												
Image processing	Radiance and reflectance computation (IDL)						■											
	Imagery coregister							■										
	Imagery normalization (IDL)								■									
	Indices calculation									■								
Field data processing (data base for calibration/validation)		■	■	■	■	■	■	■	■	■	■							
Thresholding calibration												■	■					
Classification														■				
Validation															■			
Orthorectification																■		
Mapping and final results																	■	■

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