Analysis of regional vegetation changes with medium and high resolution imagery

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ABSTRACT

The singular characteristics of the Canarian archipelago (Spain) and, in particular, of the Gran Canaria island have allowed the development of a unique biological richness. Almost half of its territory is protected to preserve the natural environment and, in consequence, the monitoring of vegetated regions plays an important role for regional administrations which aim to develop the corresponding policies for the conservation of such ecosystems. The Normalized Difference Vegetation Index (NDVI) is a common index applied for vegetation studies. It is important to emphasize that NDVI is sensor-dependent, and changes are affected by soil background, irradiance, solar position, atmospheric attenuation, season, hydric situation and climate of the area. So, a fixed threshold cannot be set, even for the same sensor or season, to properly segment vegetated areas. In this context, a robust methodology has been applied to ensure a reliable estimation of changes using the same sensor in multiple dates or different sensors. To that respect, a supervised procedure is presented consisting on the selection of different regions within each image to precisely map each cover with its associated NDVI values and, in consequence, obtain for each individual image the optimal threshold to properly segment vegetation without the need to perform the complex pre-processing required to estimate the ground reflectivity. On the other hand, fires are an important aspect of an ecosystem and their study, a fundamental task to perform a complete assessment of the environmental and economic damage. In our work we have also analyzed in detail the fire occurring during 2007 and precisely assessed the results.

Keywords: Vegetation index, NDVI, change detection, Landsat, Spot, Deimos.

1. INTRODUCTION

The Canarian archipelago has a 42% of its territory protected to preserve the biodiversity and the natural environment of these islands. In particular, almost 20% of the total area is occupied by forests. Particularly, the island of Gran Canaria has a total of 33 natural protected areas covering a 42.75% of the island surface. The World Biosphere Reserve in Gran Canaria, declared as such on 29 June 2005, covers a large section of the west of the island[1]. The aim of this declaration was the international recognition of their environmental characteristics and to consolidate a sustainable development model. In consequence, the monitoring of vegetated regions in this island plays an important role for administrations and provides fundamental information to develop the corresponding policies. Figure 1 displays the geographic extension of the different natural areas just indicated.

The Normalized Difference Vegetation Index (NDVI) is a common index applied for vegetation studies. It is sensor-dependent[2], since its value depends, not only on the net sensor system gain in the channels used, but also on the specific bandwidth and location. Furthermore, this index changes depending on the land use, the season, the hydric situation and the climate of the area. So, a fixed threshold cannot be used to properly segment vegetation areas. In this context, a robust methodology has been applied to ensure a reliable estimation of changes in green areas using multisensor or multidate data. Different strategies were assessed and a supervised procedure was employed consisting on the selection of different regions (barren land, urban, water and vegetation) within each image.

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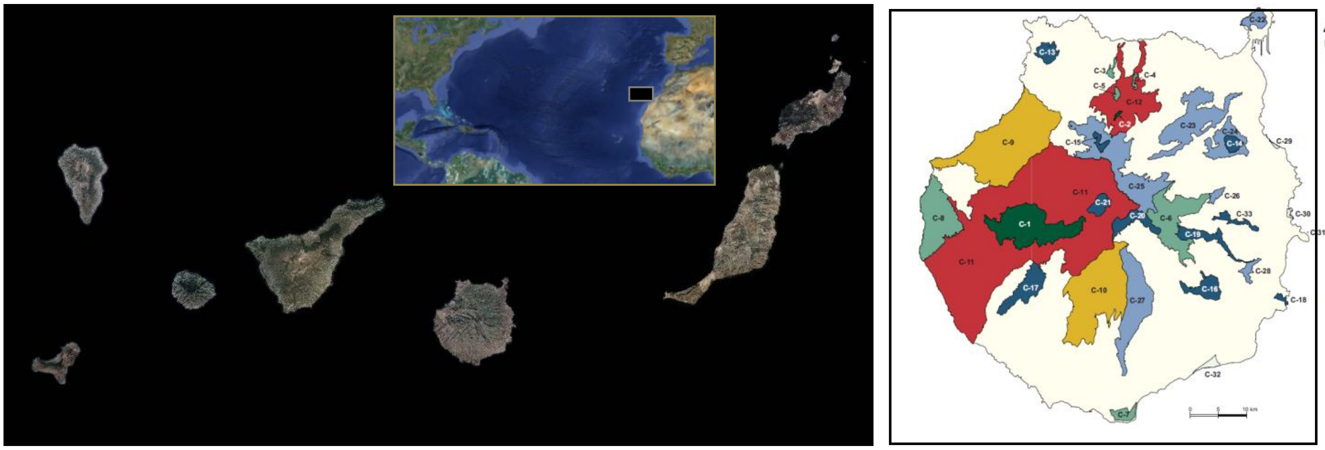
That way we can precisely map each cover with its associated NDVI ranges and, in consequence, obtain the optimal threshold to properly segment vegetation.



(a) (b)

Figure 1.(a) The Canary Islands location and, (b) Gran Canaria natural protected areas[1].

Multitemporal studies are of great interest. As indicated by Deng[3], a wide variety of digital change detection algorithms have been developed over the last two decades. They can be broadly divided into either *post-classification* change detection methods or *pre-classification* spectral change detection. In post-classification change detection, two images from different dates are independently classified and labeled. The area of change is then extracted through the direct comparison of the classification results. The advantage of post-classification change detection is that it bypasses the difficulties in change detection associated with the analysis of images acquired at different times of year or by different sensors. The major disadvantage of the post-classification approach is the high sensitivity to the individual classification accuracies. Pre-classification spectral change detection techniques rely on the principle that land-cover changes result in persistent changes in the spectral signature of the affected land surface. These techniques involve the transformation of two original images to a new single-band or multiband image in which the areas of land-cover change are highlighted. The advantage of the spectral change-detection technique is that they are based on the detection of physical changes between image dates. Typical techniques in this category are image differencing, image rationing, vegetation index differencing, principal-component analysis and change vector analysis. Despite many factors affecting the selection of suitable change-detection methods, image differencing, PCA, and post-classification are, in practice, the most commonly used methods[4].

We have developed a tool to perform a regional analysis of vegetation changes in the Canary Islands using data from different sensors. The complete methodology incorporates all the required pre-processing (radiometric calibration, atmospheric, topographic and BRDF correction) for each sensor and it can compute several indices (NDVI, RVI, EVI, SAVI, OSAVI, ARVI, etc.). Pan-sharpening techniques have been added and explored. Visual and quantitative change detection image processing techniques have also been included. Finally, we have also conducted a detailed analysis of the severe fire occurred in Gran Canaria during the summer of 2007 using the common change detection techniques and the normalized vegetation index.

This paper is structured as follows: section 2 includes the methodology used for the monitoring of green areas while section 3 presents the main results achieved. Finally, section 4 summarizes the most relevant conclusions.

2. METHODOLOGY FOR THE MONITORING OF GREEN AREAS

2.1 Remote sensing satellite data

When planning a regional analysis of vegetation change, it would be desirable to use imagery from the same sensor to keep the image characteristic as consistent as possible, but even using data from the same sensor many parameters change over the time. In our study we have finally used medium and high resolution imagery from Landsat, Deimos and Spot platforms.

The Landsat program is the longest running project for acquisition of satellite imagery of Earth. On July 26, 1972 the first satellite was launched while the most recent, Landsat 7, was launched on April 15, 1999. Landsat platforms have included different sensors but in this work we have used multispectral data from the TM and ETM+ sensors. The TM sensor includes 7 bands with 30 m resolution except for the thermal IR band (120 m), while ETM+ improves the resolution of the thermal band (60 m) and includes a new panchromatic channel (15 m). The temporal resolution is 16 days. SPOT is a high-resolution, optical imaging, Earth observation satellite system. SPOT 1 was launched February 22, 1986 with 10 m panchromatic and 20 m multispectral imaging resolution capability in 3 bands and the last of the series is SPOT 5, launched May 4, 2002 improves the resolution to 2.5 m, 5 m and 10 m capability and 4 bands plus the panchromatic one. Deimos-1 is a Spanish Earth imaging satellite launched on 29 July 2009 that belongs to the Disaster Monitoring Constellation. It carries a multi-spectral imager with a resolution of 22 metres and 600 kilometres of swath, operating in the green, red and near infrared spectral bands.

In particular, cloud free Deimos and Landsat images from 1984 to 2011 have been selected and processed to study the evolution of the total vegetation and a detailed study of a fire occurred in 2007 was performed using three specific SPOT scenes.

2.2 Data preprocessing

To properly compare pixel values from different images and, in consequence, to generate accurate results about any specific parameter from the Earth using multitemporal remote sensing imagery, a necessary preprocessing step is required for each image.

Radiometric preprocessing is applied to calibrate the image pixel values recorded by the sensor so that they represent a physical property such as the reflectance on the ground. Really, the sensor measures the energy (radiance) at the satellite level for a particular range of wavelengths. The image bands used in any study are composed by digital numbers. So, each band is processed to convert the digital numbers to at-sensor radiance values using the gain and offset information included in the image metadata. Next, at-sensor reflectance values are computed from the radiance data. However, reflectance at the Earth's surface must be accurately calculated applying the properly atmospheric correction algorithm[1, 5].

Ensuring similar atmospheric conditions between two dates is not possible as it tends to change on an hourly or daily basis and it is not always homogeneous across the image. Acquiring imagery at approximately the same time and date of the year can increase the chances of meeting this goal but it is certainly no guarantee and it also benefits to acquire images under similar solar illumination conditions and thereby shadowed and brightly illuminated areas will be similar in appearance. In any case, applying an atmospheric correction algorithm can solve some of the problem.

In addition, in any change detection study, images must be accurately aligned. So, image registration or orthorectification are necessary. In order to increase the spatial resolution, pan-sharpening can be applied, as well, if the sensor has a panchromatic band; however, this type of fusion at pixel-level alters the spectral information, even using wavelet-based algorithms, and the benefits are not totally clear.

2.3 Spectral indexes to monitor vegetation

Satellite remote sensing provides an extremely valuable data source for studying the Earth's surface at spatial and temporal scales. This technique is increasingly applied for vegetation studies. Vegetation has high absorption of the red and blue spectral regions and high reflectance in the near-infrared. Many vegetation indices have been developed to quantitatively and qualitatively study its status from satellite images. They involve combinations of spectral channels in the solar-reflected optical spectrum (400 nm to 2500 nm), usually the red and near-infrared bands, merged in such a way that they strengthen the spectral contribution of green vegetation, minimizing the disturbing influence of soil background, irradiance, solar position, atmospheric attenuation, etc. In any case, a thorough approach must include several pre-processing steps to properly correct the received bands before generating the vegetation indices. In particular, influences due to the atmosphere, the relief, the terrain, the topography and the anisotropy of land covers must be taken into account when performing regional studies.

More than a hundred vegetation indexes have been published in scientific literature, but only a small subset have substantial biophysical basis or have been systematically tested. In our case we have considered only common broadband greenness indexes as the sensors considered do not have any bands in the red-edge, short-wave IR and some specific frequencies in the near IR.

2.4 Change detection techniques

There are many types of change detection methods[3, 4]. In this work we have used the following methods based on multi-temporal time series analysis:

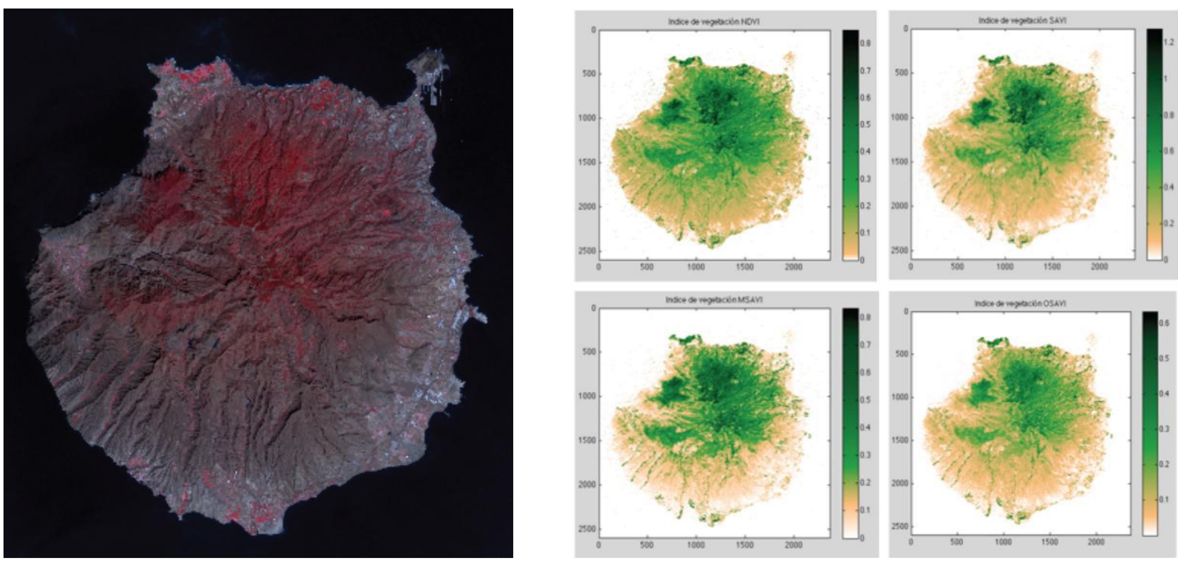
- *Visual RGB composite.* It's a straightforward change detection method providing visual information about the areas which have experienced changes. The idea is to assign to each RGB channel an image from a different date (if two images are only available, usually the first image is assigned to the R channel while the second one to the G and B channels). Results are easily interpretable and it provides an extremely quick approach to change detection.
- *Image subtraction.* It is conducted on the basis of subtracting the gray values of both images. The subtraction image shows the grey-level differences of corresponding pixels of two images. Changed and unchanged regions are determined by selecting the appropriate threshold values in the subtraction image. The gray values of the subtraction image are often approximating a Gaussian distribution, the unchanged pixels are grouped around the average value and the changed pixels are in the two tails of the distribution. The main disadvantage of this method is that it does not reflect changes in categories. The value of the subtraction image does not always show the change of the objects because of a variety of factors such as atmospheric conditions, the sun illumination, sensor calibration, and ground water conditions, etc. In actual applications, the choice of the threshold is quite difficult.
- *Principal component Analysis (PCA).* PCA is usually adopted for compression and enhancement of multispectral data. The central idea is to reduce the dimensionality of a data set consisting of a large number of interrelated variables, while retaining as much as possible of the variation present in the data set. This is achieved by transforming them to a new set of variables, the principal components (PCs), which are uncorrelated, and which are ordered so that the first few retain most of the variation present in all of the original variables. For change detection analysis, images taken at different times are combined into a single multiband image, and then the PCA is applied to obtain the PCs. Common features of the images appear in the first component while differences in the others.
- *Change detection after classification***.** Each image is classified separately and we compare the resulting images. If the corresponding pixels have the same category label, the pixel has not changed, otherwise the pixel has changed. There are supervised classification methods and non-supervised classification methods. Non-supervised classification is the process of searching and defining the spectrum cluster groups in the multi-spectral image where the computer automatically groups according to pixel spectral values or space position. Then, each group will be assigned into certain categories. Supervised classification requires the user to define areas of interest to train the classifier and assign the

remaining pixels in the image. The advantage of this change detection method is that it does not only ascertain the spatial distribution of changes but also gives the nature of changes, in other words the information on the transition from one class to another. One shortcoming is the high requirements for a reasonable classification of categories. Secondly, when the classification and change detection become two relatively independent processes, the amount of information may be reduced and the accuracy also. Finally, this method is sensitive to classification errors. Therefore, the accuracy of this method depends on the accuracy of the classification results.

3. RESULTS

3.1 Regional vegetation changes in Gran Canaria

When planning a regional analysis to assess green areas, many vegetation indices can be applied to the multispectral data. In our case we have included in our monitoring tool many of these indexes (RVI, NDVI, TVI, SAVI, OSAVI, MSAVI, EVI and ARVI). Some indexes can only be applied to Landsat images as they have the blue band. Figure 2 displays some examples of vegetation indexes applied to a Deimos-1 level 1T image acquired on October 10, 2011 at 11:40 hr.

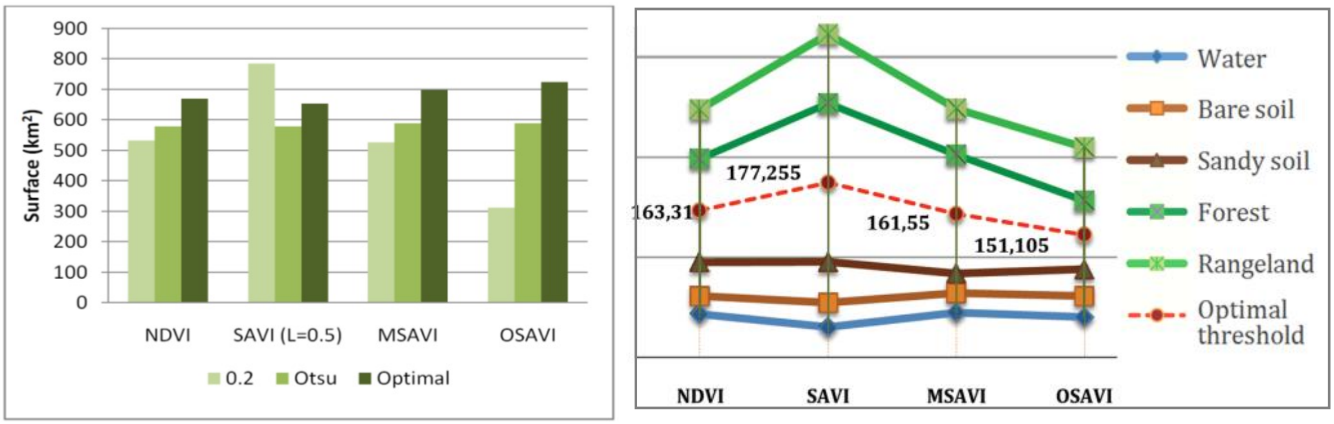


(a) (b)

Figure 2. (a) Deimos-1 false-color composite and, (b) Vegetation indexes: NDVI, SAVI, MSAVI, OSAVI.

Unfortunately, any index varies depending on the, solar position, atmospheric, soil background attenuation, season, hydric situation, etc. So, a fixed threshold cannot be set, even for the same sensor or season, to properly segment vegetation areas. As mentioned, we have tested different procedures to find out the appropriate threshold value. Finally a supervised procedure has been chosen, consisting on the selection of different regions (barren land, urban, water and vegetation) within each image to precisely map each cover with its associated vegetation index values and, in consequence, to obtain the optimal threshold to properly segment vegetation from the rest of covers. The great advantage of this method is its robustness and the possibility to apply it straight to the digital numbers, avoiding the need to perform the tedious pre-processing tasks to each image that only provide more or less accurate estimations about the surface reflectance.

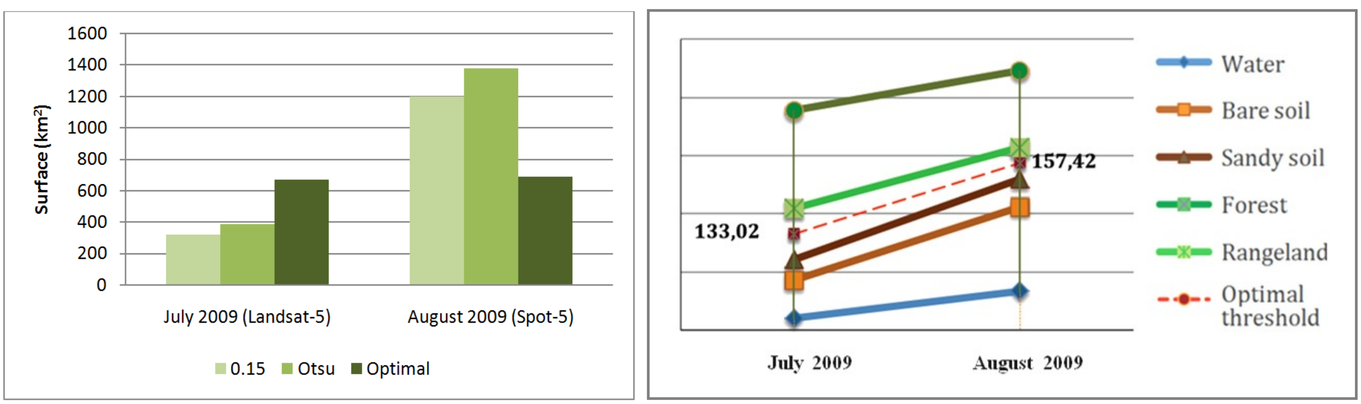
Thus, this methodology has been developed to ensure a reliable estimation of green areas using multisensory and multidate data. The key point is to obtain the appropriate threshold because, as displayed in Figure 3, minor changes in the threshold value applied involve great variations in the estimated surfaces. In Figure 3 (a), green areas are estimated using the Deimos data and the vegetation indexes of figure 2. Three cases are presented, a fixed threshold of 0.2, an automated threshold obtained by the Otsu algorithm [6] and the optimal threshold (see Figure 3 (b) where values have been rescaled).



(a) (b)

Figure 3.(a) Vegetation area obtained by different indexes with different thresholds and, (b) Optimal threshold calculation.

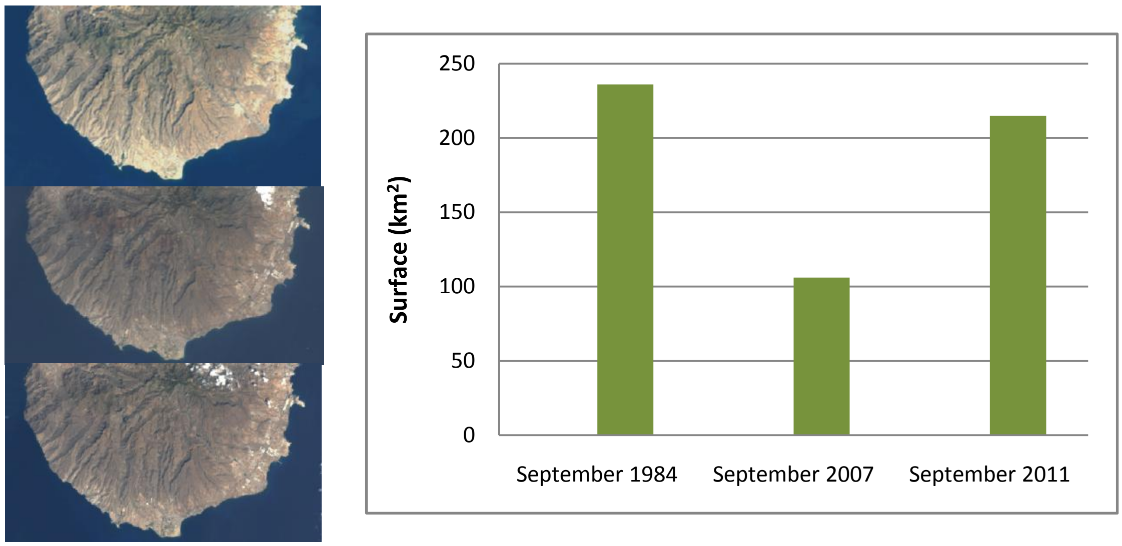
The problem about the thresholds is more clearly presented in Figure 4. In this case two cloud free images of Gran Canaria are used: one acquired by Landsat-5 on July 2009 and the other by Spot-5 on August 2009. Results for three different threshold values applied to the NDVI index are again included and it can be appreciated the robustness of the optimal threshold, providing very similar estimates of the vegetal surface for both sensors, while the remaining threshold have great discrepancies. We can appreciate that the total area of vegetation during summer of 2009 at Gran Canaria is about 680 km^2.



(a) (b)

Figure 4.(a) Vegetation area obtained by the NDVI using different thresholds for images from different sensors and, (b) Optimal threshold calculation.

Once justified the need of the optimal threshold, a temporal study has been conducted to assess the changes in the vegetation cover of Gran Canaria in the last 27 years. To that respect, three Landsat-5 images from the same month have been selected (September 22, 1984; September 22, 2007 and September 17, 2011). Figure 5 displays the results when applying the methodology to the southern part of the island as, due to the trade winds, clouds are frequently located in the northern part and it has not been possible to get cloud free images of the whole island from the same month. We can appreciate a severe decrease in green areas, estimated on 130 km^2, between 1984 and 2007. The reason was a sever fire occurring during summer 2007 where more than 100 km^2 were burnt (see next section for more details). However, we can check that reforestations activities have recover most of the forest affected.



(a) (b)

Figure 5. (a) Images and area used in the analysis and, (b) Surface covered by vegetation in the south of Gran Canaria using Landsat-5 data.

3.2 Analysis of the fire at Gran Canaria occurred in 2007

During summer of 2007 severe forest fires affected the Canary Islands. In particular, according to the Consejería de Medio Ambiente of the Canary Island Government, an area of about 20.000 hectares was burnt in Gran Canaria island (the fire was active from July 27th to August 1st). Most of the vegetation affected was the endemic pine forest and the fire had 2 phases: the first one starting on 27 and ending on 29 July with the fire considered under control. Later on, however, wind direction changed and the fire flared and spread southwards from 29 to the 1st of August. Figure 6 (a) displays the MODIS image, captured on July 30, 2007, marking out the locations of the fires on the islands of Tenerife (left) and Gran Canaria (right). Figure 6 (b)-(c) shows an example of the typical density of pine trees in the areas affected by the fire.

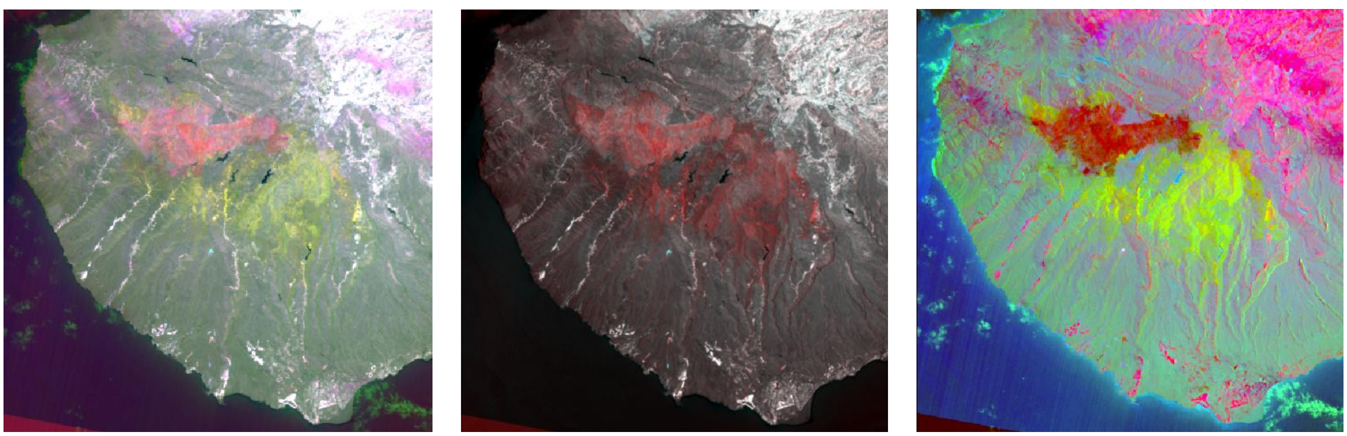
Forest fires constitute an important problem for the environment degradation. After forest fires, the burnt area and the severity of the fire need to be mapped to estimate the affected area and to plan subsequent rehabilitation tasks. In our analysis we have considered the following three SPOT images: July 2, 2007 (SPOT 2 - HRV1), July 29, 2007 (SPOT 2 - HRV2) and August 4, 2007 (SPOT 5 - HRG2). SPOT 2 images have been resampled as their spatial resolution is 20 m while the SPOT5 resolution is 10 m.

(a) (b) (c)

Figure 6. (a) MODIS-Aqua color composite of July 30, 2007, (b) pine trees burnt during the fire and, (c) example of an area burnt.

In order to analyze and quantify the changes due to the fire, we applied the change detection techniques mentioned in section 2.4 and a summary of the results obtained are as follows:

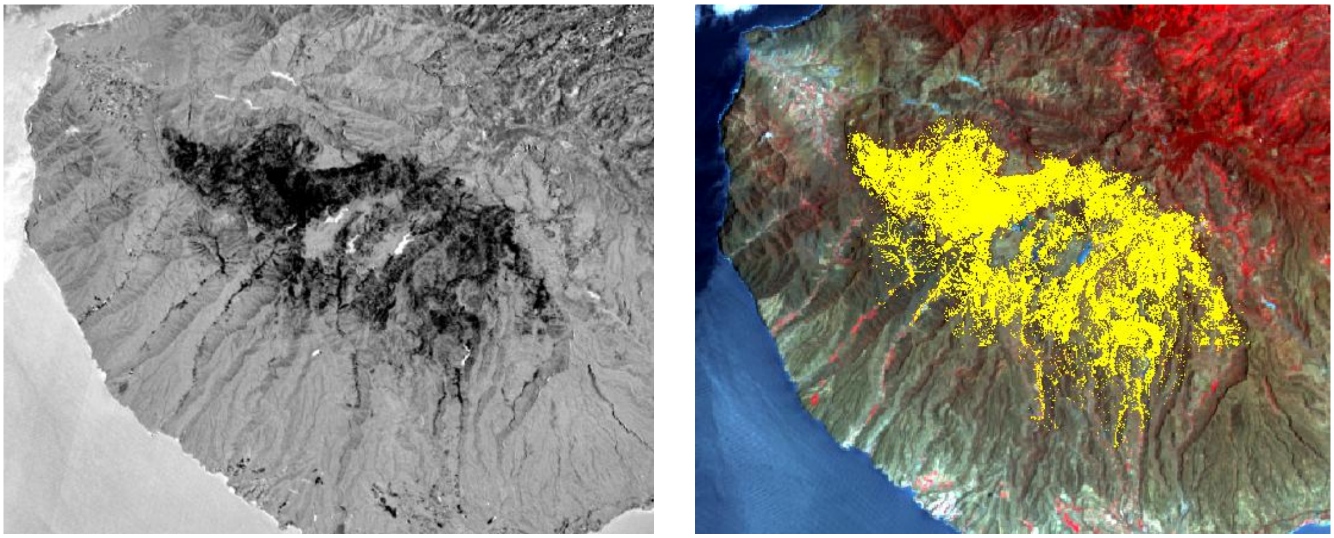
- *Visual RGB composite.* We can see in figure 7 (a) that have assigned each NDVI image from a different date to each RGB channel while in figure 7 (b) only two images have been used: the first NDVI image assigned to the R channel while the last one to the G and B channels. We have also included the color composite of the 3 principal component (PC) bands generated from the three original NDVI image. Color composites using 3 images clearly identify the two different phases of the fire while the case with 2 bands displays in red the total area affected.



(a) (b) (c)

Figure 7. Color composites highlighting the changes: (a) NDVI 1, 2 and 3, (b) NDVI 1 and 3 and, (c) PC 1, 2 and 3 obtained from the three NDVIs.

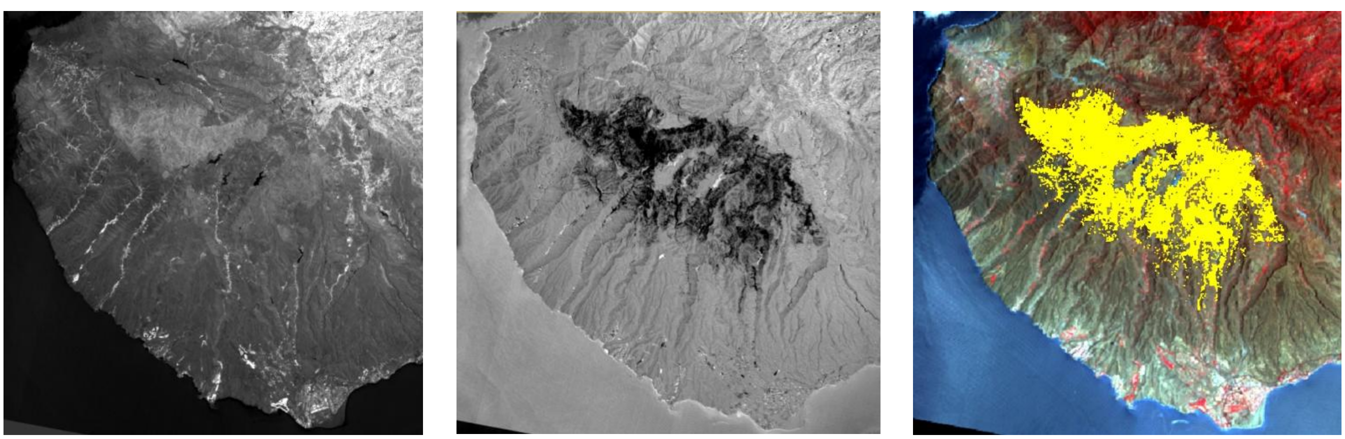
- *Image subtraction.* We have considered just the subtraction between the first and the last NDVI image to estimate the overall surface affected. Figure 8 shows the grey-level differences while changed regions (yellow pixels) due to the fire were determined applying the appropriate threshold in the subtraction image. In our case, after the analysis of the histogram and the difference values in some areas of the image, a threshold of 0.15 was selected. The total area of vegetation burn in the fire zone was estimated in 10.449 ha.



(a) (b)

Figure 8. (a) Difference image after the subtraction of both NDVIs images and, (b) estimated burnt area overlaid on the color composite of the scene on July 2, 2007.

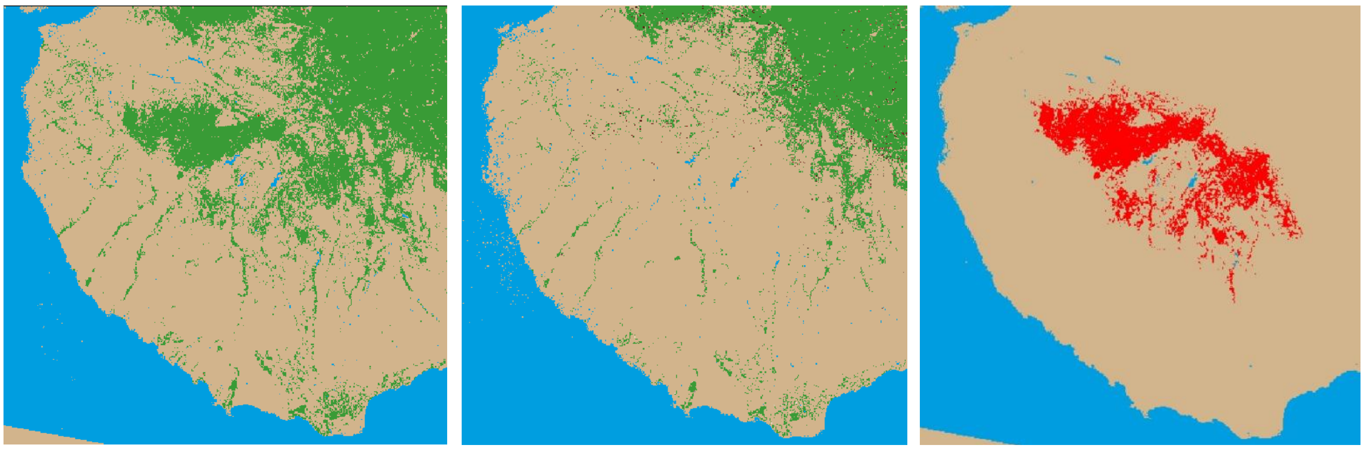
- *Principal component Analysis.* We have applied this transformation to a stack image with the first and last NDVI. Figure 9 presents both principal components and the estimated burnt area after applying the appropriate threshold to the second component. In this case 10.818 ha were obtained.



(a) (b) (c)

Figure 9. (a) First principal component of both NDVIs, (b) second principal component and, (c) estimated burnt area overlaid on the color composite of the scene on July 2, 2007.

- *Change detection after classification***.** We tested this change detection methodology applying an unsupervised classifier with 3 classes (water, soil and vegetation) to different possibilities of input images: original multispectral bands, PCA bands, NDVI bands, stacked PCA and NDVI, difference bands, etc. Finally, the best results (figure 10) were achieved separately classifying each NDVI band and computing the difference of both thematic images. The Isodata algorithm was used and 10 classes were originally considered and then merged to the 3 thematic clusters of interest. The estimated burnt area (red pixels) was of 8.648 ha.



(a) (b) (c)

Figure 10. (a) Isodata classification of the first NDVI First principal component of both NDVIs, (b) second principal component and, (c) estimated burnt area overlaid on the color composite of the scene on July 2, 2007.

Some discrepancies can be appreciated in our analysis and as well in previous studies[7-9], where the burnt area estimated by the Canary Islands government is about 20.000 ha, by the Spanish Ministerio de Medioambiente y Medio Rural is 18.786 ha, by the German DLR and the Joint Research Center is 15.350 ha (9900 fully burnt and 5450 partially burnt) and by the Spanish INIA (Instituto Nacional de Investigaciones Agrarias) is 15.737 ha. We have to take into account that in our study we are using NDVI images, so we are just considering the vegetal areas burn (mainly Canarian pines) and not the total surface affected.

4. CONCLUSIONS

The island of Gran Canaria has almost half of its territory protected to preserve the natural environment; thus, the monitoring of vegetal regions plays an important role for regional administrations. A tool for regional vegetation analysis has been developed and applied to monitor the vegetation variations using with medium and high resolution imagery.

Vegetation indexes vary depending on the solar position, atmospheric, soil background attenuation, season, hydric situation, etc. So, a fixed threshold cannot be set, even for the same sensor or season, to properly segment vegetation areas. We tested different procedures to find out the appropriate threshold and a supervised procedure was selected, consisting on the analysis of the vegetation index values for different regions (barren land, urban, water and vegetation) to obtain the optimal threshold to differential vegetation from the remaining covers. This method is robust and can be directly applied to the digital numbers, avoiding the need to perform the complex pre-processing corrections. Using this methodology we can state that, in general, the health of forests and vegetation covers of Gran Canaria is fine after 27 years, even after the big fire of 2007 because the burnt areas have recovered due to both natural and reforestation phenomena.

On the other hand, we have also analyzed in detail the fire occurring during 2007 and the burnt area was assessed using different change detection techniques (color composites, image subtraction, PCA and classification). In summary, the vegetal area affected was estimated in about 10.000 ha.

5. ACKNOWLEDGEMENTS

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REFERENCES

[1] http://www.figurasdeprotecciondegrancanaria.es/ (July 2012)
[2] Purkins, S. and Klemas, V., [Remote Sensing and Global Environmental Change], Jonh Wiley & Sons, Oxford (2011).
[3] Deng, J. S., Wang, K., Deng, Y. H. and Qi, G. J., "PCA-based land-use change detection and analysis using multitemporal and multisensor satellite data," International Journal of Remote Sensing, 29(16), 4823-4838 (2008).
[4] Lu, D., Mausel, P., Brondizino, E. and Moran, E., "Change detection techniques," International Journal of Remote Sensing, 25, 2365–2407 (2004).
[5] Horning, N. Robinson, J. E., Sterling, E. J., Turner, W. and Spector, S., [Remote Sensing for Ecology and Conservation], Oxford University Press, Oxford (2010).
[6] Sankur, B. and Sezgin, M., "A Survey Over Image Thresholding Techniques and Quantitative Performance Evaluation," Journal of Electronic Imaging, 13(1), 146-165 (2004).
[7] Huesca, M., González-Alonso, F., Cuevas, J. M. and Merino de Miguel, S. "Estimación de la superficie quemada en los incendios forestales de Canarias en 2007 utilizando sinérgicamente imágenes MODIS y anomalías térmicas," Investigación Agraria: Sistemas y Recursos Forestales, 17(3), 308-316 (2008).
[8] http://www.zki.dlr.de/article/858 (July 2012)
[9] Alonso-Benito, A.; Hernández-Leal, P. A.; González-Calvo, A.; Arbelo, M. and Barreto, A. "Comparación de diferentes técnicas para la estimación de áreas quemadas en un entorno insular,". Tecnologías de la Información Geográfica para el Desarrollo Territorial. Servicio de Publicaciones y Difusión Científica de la ULPGC. Las Palmas de Gran Canaria. (2008).