MULTI-TEMPORAL WOODY PERENNIAL VEGETATION COVER CHANGE DETECTION

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Abstract

During the last decades, large scale detecting, measuring and monitoring of land-use and land-cover changes (LUCC) has been given a significant boost with the advent of remote sensing data. In Australia, the Commonwealth Scientific and Industrial Research Organisation (CSIRO), in partnership with the Australian Greenhouse Office (AGO), have developed a series of algorithms and methods which are being operationally used for large-scale LUCC and monitoring. The present study gives a short overview of these remote sensing techniques and demonstrates their applicability in the Mediterranean region using a Spanish coastal area as the trial site. Landsat TM and ETM data from various dates spanning 15 years (1987 - 2001) are used to map changes in the extent of woody perennial vegetation cover. A rigorous accuracy assessment is undertaken producing accuracy figures above 97% for both types and all dates. Some recommendations are made for the successful application of the methodological framework in the Mediterranean region.

KEY WORDS: Forest cover change, multi-temporal mapping, Landsat, Mediterranean

1. Introduction

It has been widely investigated and documented (Brandt and Thornes, 1996) that over the last several decades the Mediterranean region has been subjected to major changes in land use/cover as a result of forest fires, the abandonment of farms and grazing land, the relocation of people to the coastal border, the rapid expansion of tourism-related activities, and the intensification of agriculture, among others. Specifically, forest fires are seen as one of the most important driving factors of the observed land degradation in the region (Symeonakis *et al*., 2007; Vafeidis *et al*., 2007).

Spain, in line with the observed trends in other Mediterranean European countries, has seen a dramatic increase in the number of fires over the last decades. There is an urgent need for accurate monitoring methods that would allow for the identification of any decreasing trends in woody perennial vegetation cover density and the adaptation of measures for its reversal. Previous research has shown that remote sensing data are useful for this. In Australia continental-scale mapping and monitoring of the extent of woody perennial vegetation (hereafter referred to as 'woody vegetation'), is being performed by the National Carbon Accounting System (NCAS) Landcover Change Project (http://www.greenhouse.gov.au/index.html; Caccetta et al., 2003; Richards and Furby, 2002). The programme is based on algorithms and methods developed by the CSIRO, in partnership with the AGO, applied to the time series of Landsat imagery. The CSIRO/AGO methodology has recently been applied in a Spanish area as a trial of its applicability in a Mediterranean environment. This paper provides an overview of the remote sensing techniques and the results of their application in a Spanish Mediterranean area for mapping woody vegetation cover and its declining, increasing or stabilising trend. The data processing and woody vegetation cover change results are presented, problems arising from the specific datasets are discussed and recommendations are made.

2. Case study

The trial site in Spain is composed by a system of valleys (Canyoles and L' Albaida valleys) and mountain ranges (Serra d' Enguera, Grossa and de la Solana), belonging to the Pre-betic system (SW-NE orientation). It lies between the Spanish Provinces of Albacete, Alicante and Valencia (*Figure 1*). It covers an area of approximately 550 km^2 and is characterised by a complex topography, which ranges between 250 to 1000 m above sea level. The basins are Miocene marls whereas the ranges are mainly composed of Cretaceous limestones. The climate is typical of the Mediterranean region, with hot and very dry summers, and higher precipitation amounts in autumn. Mean annual rainfall and temperature is 550 mm and 13.86ºC, respectively. Natural vegetation is mainly developed on the range systems, and developed on limited soil depths. It is composed of *Pinus halepensis* and Mediterranean esclerophic scrubs (as *Pistacia lentiscus*, *Quercus coccifera, Rosmarinus officinalis, Ulex parviflorus*), with different density cover according to its degradation state. Nevertheless, the valleys are extensively cultivated with unirrigated types such as olive trees and vineyards. Residential and urban use in this area still maintains a predominant concentrated model, even though, the general trend in the region is an increase of the dispersed one. Under such environmental conditions and human pressure, forest fires are a frequent phenomenon.

Figure 1. Location of Spanish trial site (map source: www.spain-holiday.com)

3. Datasets and methods

3.1 *Data*

Five TM and ETM+ images were used spanning 15 years from 1987 till 2001. Ideally, images would be acquired during the summer to early autumn months (June to September). However, budget limitations on the one hand and availability of cloud-free data on the other led to the choice shown in *Table 1*:

	Date	Sensor & Source
1	13 August 1987	Landsat 5, TM, Eurimage
2	*20 April 1992*	*Landsat 5, TM, Global Land Cover Facility (GLCF)*
3	29 June 1994	Landsat 5, TM, Eurimage
4	*8 August 2000*	*Landsat 7, ETM+, Joint Research Centre (JRC)*
5	*8 June 2001*	*Landsat 7, ETM+, GLCF*

Table 1: Landsat data used and their source. Free data are depicted in italics.

The Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) of the United States Geological Survey (USGS) with a horizontal resolution of 90m was used in this trial. It is available freely by the GLCF and the Consultative Group for International Agriculture Research's Consortium for Spatial Information (CGIAR-CSI). The SRTM DEM was first re-projected to the projection used in the trial exercise (UTM, zone 30 North; datum: WGS84). The two versions available by the CGIAR-CSI and the GLCF were combined to fill in the no-value cells that appear in both due to terrain effects. Finally, sinks were filled to create a 'depressionless' DEM, using the GRID module of ArcInfo (ESRI, 1995).

Ideally, local knowledge, ground data and high-resolution aerial/satellite images are used to identify sites of desired land cover types in the study area and their change through time. However, it is often the case that validation data exist only for a limited number of dates. In this trial, training and validation data came from the following sources: (i) 1:18000 aerial photographs of 1977; (ii) 1:25000 aerial photographs of 1991; (iii) 1:25000 orthophotos of 1998 from Sig-oleícola (http://www.mapa.es/es/sig/pags/sig/intro2.htm), and (iv) 1:25000 colour orthophotos of 2002 from Sigpac (http://www.mapa.es/es/sig/pags/sigpac/intro.htm). The validation area was reduced to 90% of the original study area because of issues related with the availability of ground reference data for the entire period of study.

3.2 *Methodology*

The time series Landsat data were registered and ortho-rectified using the 2001 GLCF free ortho-rectified image as reference. Around one hundred GCPs were collected from it for rectifying the two Eurimage scenes and to check the ortho-rectification of the 2000 JRC image. Cross-correlation feature matching techniques were employed to improve the speed and accuracy of co-registration of the images to the rectification base (Caccetta et al., 2007). Ortho-rectification was then achieved using a rigorous earth-orbital model with PCI OrthoEngine (PCI Geomatica 2003).

The orthorectified images were then calibrated by converting their raw digital counts to be consistent with the reference image of 2001. Three calibration steps were applied, namely Top-Of-Atmosphere (TOA) reflectance calibration (Vermote et al., 1994), Bi-directional Reflectance Distribution Function (BRDF) calibration (Wu et al., 2001), and terrain illumination correction (Wu *et al*., 2004) based on the C-correction (Teillet et al., 1982).

A Canonical Variate Analysis (CVA; Campbell and Atchley, 1981) of the ground and spectral data was then undertaken to investigate the spectral separability of the woody and non-woody vegetation training sites. Also, linear combinations of image bands (or indices) were used to discriminate between the two classes. The resulting indices were applied to all images in the sequence:

Index 1 = band3 + band5; and

Index 2 = band4 – band2.

Thresholds that define the boundary between the certain woody vegetation spectral region and the uncertain spectral region were set so that no commission errors were made. Furthermore, additional thresholds were identified that distinguish between the uncertain areas and the certain non-woody vegetation spectral regions so that no omission errors were made. At first, these thresholds were identified from the training data. They were then refined by considering the entire image area. The previously applied calibration meant that the thresholds derived for the 2001 image could be applied to the other time slices of the same season (i.e. the 1987, 1994 and 2000 images). The thresholds were adjusted for the 1992 spring image. The indices and thresholds were used to calculate a probability of woody cover image for each time frame in the following manner:

- Pr(woody) = 1 for pixels with index values in the certain woody vegetation spectral region.
- Pr(woody) = 0 for pixels with index values in the certain non-woody vegetation region.
- 0 < Pr(woody) < 1 for pixels with index values in the uncertain spectral region (based on the closeness to the 'certain woody vegetation' thresholds).

Within the uncertain spectral region, additional information was used to label a pixel as 'woody vegetation' or 'non-woody vegetation'. This was derived from the pattern of index values through time.

A joint model for multi-temporal classification using conditional probability networks (CPNs; Caccetta, 1997; Kiiverii and Caccetta, 1998) was then specified. This approach exploits the observation that many commission errors due to land management practices vary more rapidly compared with woody vegetation processes. Temporal rules are used to minimise the probability that such areas are labelled 'woody vegetation' in any year. The input to CPN are the five woody cover probability images calculated from the indices and the thresholds and a series of files that describe the relationships, or rules, between the CPN variables, i.e. the true and the estimated woody cover maps. The output of the CPN is a new probability image for each time-frame. These are the modified probabilities that have been altered by the rules providing more consistent cover estimates through the years.

Woody cover change and trends in the density of woody cover were also mapped (Wallace and Furby 1994). 'Woody/non-woody' masks for each date were first formed (from the modified probability maps produced from the CPN) and compared to produce woody cover change maps. To map the trends in density, the methodology exploits the fact that lower values of the first index (i.e. band3+band5) correspond to denser woody cover and higher values to less dense. Areas of increasing woody cover appear to have lower index values in the later years than in the earlier ones. Conversely, areas with decreasing woody cover show higher index values in the later years than in the earlier ones. Areas that have been through some sort of disturbance (e.g. fire, grazing, etc.) but then recover have index values that are low in the early years, higher in the middle and then tend to return towards the lower values. The curves are summarised by their slope and curvature. Areas that are stable have slopes near zero; gradual trends have low slopes whereas sudden disturbance events will generally have higher slopes. The curvature also shows whether an area has partly or fully recovered from a disturbance during the period of interest. The above trends are summarised by fitting the linear and quadratic components (i.e. the slope and curvature) of the response through time. In order to get independent estimates of the two parameters, orthogonal polynomials are used for the fitting process (Draper and Smith, 1981).

4. Results

4.1 *Rectification*

The overall size of the mean errors (RMSE) was around 10m in both directions for all images, which is less than one pixel. However, absolute pixel errors of more than one pixel can also be a cause of concern in multi-temporal studies. According to the output plots of the image matching program used to check the registered 2000 JRC image to the 2001 GLCF base image, there appears to be a systematic concentration of both low and high negative residuals in the y-direction. On the x-direction, two concentrations of relatively low values were also detected.

4.2 *Multiple year processing results*

The multi-temporal processing was performed using conditional probability networks (CPNs) with a view to reducing the amount of false change detected when comparing two woody cover maps of any two dates. In Figure2 an example is presented for a sample area for the year 1994 (*Figure 2a*) and 2001 (*Figure 2b*).

Figure 2c is the prior woody vegetation (probability) maps displayed simultaneously for 1994 and 2001. *Figure 2d* is the modified woody (probability) maps for 1994 and 2001 estimated by weighing relationships between the CPN variables accordingly to reflect the time interval between image dates; and *Figure 2e* is the modified probability maps with relationships between the CPN variables considered equally 'important', irrespective of the time interval between images.

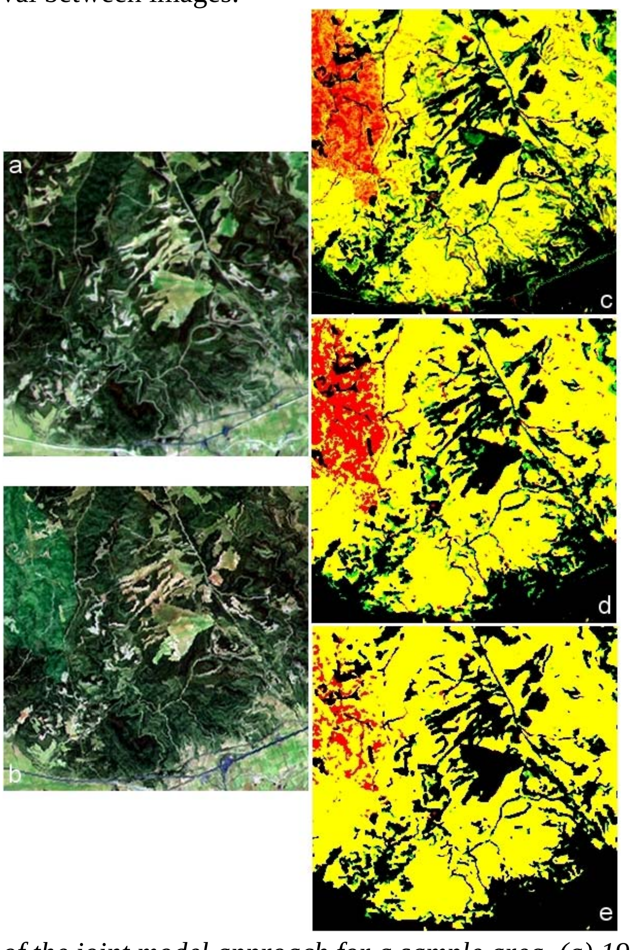

Figure 2. A demonstration of the joint model approach for a sample area. (a) 1994 image. (b) 2001 image. (c) Prior woody probability map. (d) Modified woody probability map with relationships between the CPN variables weighted accordingly to reflect the time interval between image dates. (e) Modified woody probability map with relationships between the CPN variables considered equally 'important' irrespective of

the time interval between images. Most of the false change in (c) has been removed by the time-series processing. (In (c), (d) and (e), the 1994 data are displayed in red and the 2001 in green).

4.3 *Validation results*

Validation was performed by photointerpretation using homogeneous polygons as sampling units in a stratified random sampling frame across the woody and non-woody areas. Firstly, we created 500 polygons across the study area. The number of polygons per cover type (woody and non-woody) was proportional to the area covered by each type in each year. The polygon positions were randomly defined as points with a distance of 200m between them. The random points were converted to square polygons of 5 x 5 Landsat pixels (15625 m^2). The sampling polygons were then reduced to homogeneous land-cover classes according to the reference aerial photos, avoiding woody/non-woody boundaries. In some cases, the shape and size of the polygons were changed to follow the ground cover morphology, making sure they always measured the equivalent of at least four Landsat pixels (2500 m^2). When a sample polygon was smaller, a new one was added to compensate. *Table 2* shows the accuracy figures for the different dates for woody and non-woody cover types. Overall accuracies are high and range between 97 and 99%. It is interesting to note that percentage correct for woody cover for the two ETM+ images (2000 and 2001) reaches that of perfect estimates (1000%).

	1987	**1992**	**1994**	**2000**	**2001**
Overall Correct %	97	99	98	98	99
Correct woody (%)	98	99	98	100	100
Correct non-woody (%)	97	99	98	99	99

Table 2: Overall accuracy (%), % correct for woody and non-woody cover types for the five dates of the case study

4.4 *Change maps and Density trends*

Figure 3 is a sample woody trend map between 1987 and 2001. Both the quadratic and linear trends are displayed. Areas in shades of red indicate an overall decline in cover density from 1987 to 2001. Shades of blue are indicative of an overall improvement in woody cover for that period. Areas shaded in green have been disturbed but are recovering back to the 1987 woody cover level. Yellow and cyan show patterns of disturbance but with partial recovery.

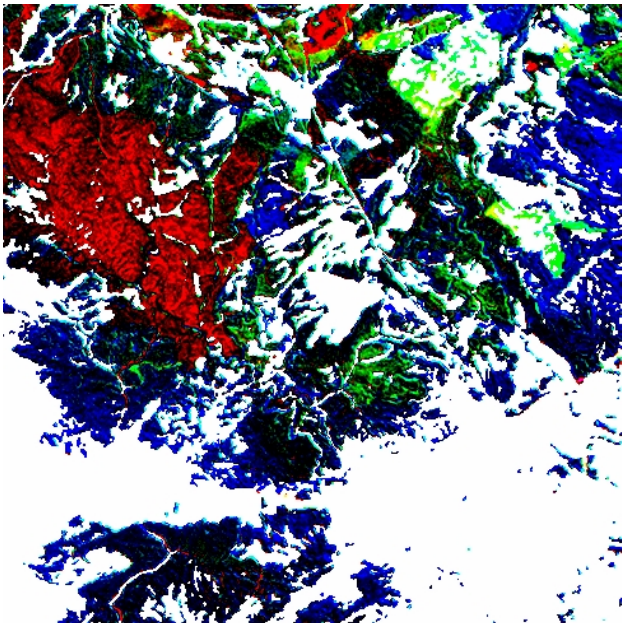

Figure 3. Linear and quadratic temporal trends for a sample area. Shades of blue represent an increasing trend; shades of red a declining trend. Greens are areas that have been disturbed but are recovering whereas mixed colours (yellow and cyan) are areas that have been disturbed and only partially recovered. Stable areas are depicted in black. White are the non-woody areas.

5. Discussion

Ortho-rectification plays a critical role in the whole change mapping process. If time-series images are misregistered, the same pixel on different images will be shifted causing serious problems for tracking land cover change through time. The existence of systematic concentrations of residuals that the image-matching between the orthorectified JRC and GLCF images revealed, is indicative of the care required for using such data for multi-temporal mapping of land use/cover changes.

Some terrain effects were removed but many finer ones, especially on north-facing steep slopes, persisted. This is largely caused by the coarse resolution SRTM DEM. A finer-resolution DEM, ideally of the same (or better) resolution as the Landsat scenes would improve the corrections, as discussed in Wu *et al*. (2005). Calibration produced good results for all but one image thus reducing the number of reliable images left for the multi-temporal processing even further to four, including the phenologically different spring image of 1992.

Forested surfaces in this area are mainly composed of discontinuous pine trees mixed with typical Mediterranean woody shrubland species (i.e. dense matorral). The classification methodology presented here allows for a good detection of natural continuous vegetated areas with these characteristics as it is capable of discriminating from non-forested areas (such as olive or almond groves) or highly dispersed natural vegetation without enough continuity to be considered as forested areas. Moreover, the analysis of density trends provided an insight to the dynamic process of degradation (e.g. through fire) or regeneration of the vegetative cover (e.g. reforestation) or the more subtle processes brought about by natural processes, such as recovery, stabilization or regression.

On the whole, the CPN produced reasonable modified woody probability maps. It smoothed out single-date classification error and also removed some of the remaining terrain-induced error effects on the prior probability maps. One consequence of the CPN approach is that although long term land cover change (e.g. clearing for agriculture, etc.) is accurately mapped, more ‘transient’ change, only appearing in one image date, can be over-smoothed. For example, the information on clearing of forest which then re-grows before the next imagery may be lost in the multi-temporal CPN processing. A denser time-series is therefore needed for the accurate mapping and monitoring of woody cover. Depending on the particular question being studied, yearly data should probably be used.

6. Conclusions

There is an urgent need for accurate woody perennial vegetation cover mapping methods that would allow for the identification of any decreasing trends in woody cover density and the adaptation of measures for its reversal. The CSIRO/AGO methodology based on multiple year processing of remote sensing data can provide a powerful monitoring tool of Mediterranean woody perennial vegetation areas producing highly accurate (between 98% and 100%) woody vegetation cover maps. The methodology also produces an insight in the trend of the density of woody vegetation cover allowing for an appraisal of any disturbance, with or without recuperation.

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