MULTI-TEMPORAL LAND USE/COVER CHANGE DETECTION IN THE SPANISH MEDITERRANEAN COAST

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ABSTRACT:

Land-use and land-cover changes (LUCC) are significant to a range of themes and issues central to the study of global environmental change. During the last decades, large scale detecting, measuring and monitoring of LUCC has been given a significant boost with the advent of remote sensing data. In Australia, time-series of remotely sensed satellite imagery is routinely used, along with ground information, to form multi-temporal classifications of the presence/absence of woody perennial vegetation. 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 the last 15 years are used to map changes in the extent of forest cover. Initial assessment of the results estimates the accuracy of the methods at 91% for forest cover. Recommendations are made for the successful application of the methodological framework in the Mediterranean region.

1. INTRODUCTION

Continental-scale mapping and monitoring of the extent of forest and woody perennial vegetation, is being performed in Australia by the National Carbon Accounting System (NCAS) Landcover Change Project. The project extends to the entire Australian continent and produces maps of change in forest and other types of cover from an archive of Landsat images currently numbering approximately 5000 scenes (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 methodology has recently been tested in a Mediterranean region of Spain as a trial of its applicability in a different environment, which is the topic of this paper.

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*., 2004; Symeonakis *et al*., in press). This paper provides an overview of the remote sensing techniques and the results of their application in a Spanish Mediterranean area for mapping forest cover and its declining, increasing or stabilising trend.

2. METHODOLOGY

The image processing methodology performs the following steps (Furby, 2002):
1. Selection of Landsat scenes and registration of time series Landsat data.
2. Calibration of Landsat data to a common reference (Furby and Campbell, 2001).
3. Processing of the calibrated data to remove 'corrupted' data, (drop-outs, data affected by fire, smoke and cloud, etc.).
4. Terrain illumination correction of the calibrated data to adjust for differential viewing geometry (Wu *et al*., 2004).
5. Stratification of the data into 'zones', where land cover types within a zone have similar spectral properties;
6. Discriminant analysis of ground data and spectral data to determine a single-date classifier to produce a series of classification maps; and
7. Specification of a joint model for multi-temporal classification (Kiiveri and Caccetta, 1997).
A brief presentation of steps 1, 2, 4, 6 and 7 is provided here. For a thorough description of each of these methods see Furby (2002).

2.1 Image Rectification

Two main steps are used to establish a rectified sequence of Landsat imagery:
1. establish a common ortho-rectified base;
2. ortho-rectify temporal sequence of images to the common base.

A rigorous earth-orbital model in PCI OrthoEngine (www.pcigeomatics.com) is used. After establishing an ortho-rectified base, ground control points (GCPs) are automatically matched using a cross-correlation technique (Furby, 2002 pp. 24-31). Visual inspection and a numerical procedure based on cross-correlation feature matching are used in quality assurance to assess the accuracy of co-registration of the series of images to the base.

2.2 Image Calibration

Ideally, all images would be calibrated to standard reflectance units. However, when comparing images to detect change, it is sufficient to convert raw digital counts to be consistent with a chosen reference image. Three calibration steps are applied in the radiometric correction procedure for Landsat imagery (Wu *et al.*, 2005):

1. Top-Of-Atmosphere (TOA) reflectance calibration (also called sun angle and distance correction)

The TOA calibration is to correct the reflectance differences caused by the solar distance and angle. The sun zenith and azimuth angles for each pixel and the distance from the scene centre to the sun are calculated and the reflectance correction is then calculated for each band as described in Vermote *et al.*, (1994).

2. Bi-directional Reflectance Distribution Function (BRDF) calibration (Danaher et al., 2001)

Angular effects across a Landsat scene result in BRDF effects which are relatively small, but significant in the context of broad-scale monitoring. The BRDF correction is a linear function of scan angle which is applied to each band. A two-kernel empirical BRDF model was applied to correct the remaining scene-to-scene differences. Simple variations of Walthall's model (Danaher *et al.*, 2001), were used in the BRDF calibration approach (Wu *et al.,* 2001).

3. Terrain illumination correction

This step is required where there are significant terrain illumination effects, resulting in brighter and darker sides of hills and mountains. This is particularly important for time series imagery as terrain effects may vary with different dates. The details of the terrain illumination correction used can be found in (Wu et al., 2004), which is based on the C-correction (Teillet *et al.,* 1982) and incorporates a ray-tracing algorithm for identifying true shadow. As discussed in Wu *et al.* (2005), a high-resolution digital elevation model (DEM) is required to achieve adequate removal of terrain effects.

2.3 Classification

Band reduction routines related to canonical variate analysis (CVA) are applied to identify the important spectral band combinations for the questions of interest. Related routines (McKay and Campbell 1982) are then used to smooth the band coefficients to derive simplified spectral indices. Instead of modelling the spectral data using multivariate Gaussian distributions, index thresholds are derived for producing the single date classifications. In order to avoid producing 'hard' classifications, intervals between these thresholds are also used. The classification process consists of two major steps:

a) Derivation of linear combinations of bands (or spectral indices) which `best' separate the classes in spectral space;

b) Specification of decision boundaries (or thresholds) for mapping spectral space into the specified classes: forest and non-forest.

First, a set of spectral indices is chosen for one image. The thresholds are then adjusted for each image of the time series to account for seasonal variation and limitations in the accuracy of calibration.

2.4 Spatial Temporal Models

The time series of classification maps is derived from images of varying quality and spectral discrimination. To improve classification accuracy, a spatial-temporal model which allows sequences of satellite images to be integrated with other spatial data to accurately map the extent of forest cover over time is used. The model is a conditional probability network (CPN) (Caccetta, 1997, Kiiveri and Caccetta, 1998). It enables uncertainties in the available data to be propagated through the calculations and to be represented in the output products. The probabilities from neighbouring dates are used to modify the probabilities of each pixel. The effect of the method is that it 'smoothes out' sudden changes and reduces uncertainty and errors in the individual dates. The result is a series of modified probability maps for each date.

2.5 Land cover change maps and density trends

'Forest/no-non-forest' masks for each date are then formed from the modified probability maps produced from the CPN model. These are then compared to form the change maps. The last step in the methodology is to look at trends through time in forest areas (Wallace and Furby, 1994).

3. SPANISH TRIAL

As part of an EU-funded project which involves the collaboration between the Australian CSIRO and the University of the Aegean (Greece), a trial using the above algorithms and methods for mapping and monitoring forest change in the Mediterranean region was performed. In this section, the data processing and forest cover change results are presented, problems arising from the specific datasets are discussed and recommendations are made.

3.1 The study area

The trial site in Spain is the extent of the Landsat scene with WRS-2 path and row numbers 199 and 33, respectively (Figure 1). It lies between the Spanish Provinces of Albacete, Alicante, Cuenca, Murcia and Valencia. It covers an area of approximately 38000 km^2 and is characterised by a complex topography which ranges from 0 to 1545 m above sea level.

Figure 1. Location of Spanish trial site (map source: multimap.com)

3.2 The data

3.2.1 The satellite 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:

	DATES	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 green.

3.2.2 The Digital Elevation Model (DEM)

The Shuttle Radar Topography Mission (SRTM) 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 (http://www.landcover.org) and the Consultative Group for International Agriculture Research's Consortium for Spatial Information (CGIAR-CSI). The following pre-processing steps were applied to the SRTM DEM:

- Re-projection to the projection used in the trial exercise: UTM; zone: 30 North; datum: WGS84;
- Combination of the two versions available by the CGIAR-CSI and the GLCF to fill in the no-value cells that appear in both due to terrain effects;
- Creation of a 'depressionless' DEM using the GRID module of ArcInfo to fill in the sinks.

3.2.3 Training and validation data

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 in the form of a free 'virtual fly-through' facility of the Instituto Cartogràfico Valenciano (http://www.gva.es/icv/). The facility uses orthorectified and seamlessly mosaiced 1:25000 colour aerial photographs, taken between 2000 and 2003 and covering the three Provinces of the Region of Valencia (i.e. Alicante, Castellón, and Valencia). Therefore, it was only the 2001 forest/non-forest map that was validated.

3.3 Results

3.3.1 Rectification and calibration

The free Landsat data (from the GLCF and the JRC), are available as ortho-rectified images. The 2001 image was chosen as the ortho-rectification 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. 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.

Figures 2a and 2b are samples from the 1994 and 2001 ortho-rectified images. Figure 2c is the sun-shaded SRTM DEM for the same area and Figures 2d and 2e are the outputs of the terrain illumination correction for the same area. Most of the illumination effects were removed.

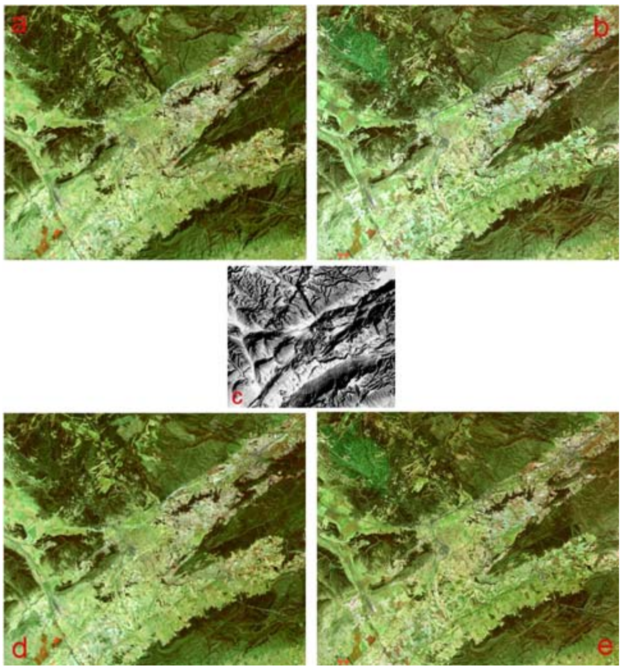

Figure 2. Sample images before and after terrain correction for 1994 (a and d) and 2001 (b and e) and the respective sample of the sun-shaded SRTM DEM (c).

3.3.2 Indices and thresholds

Canonical variate analysis (CVA; Campbell and Atchley, 1981) was used to investigate the spectral separability of the forest and no-forest training sites. Linear combinations of image bands, or indices, were used to discriminate between the two classes. The process was applied to three different zones in the 2001 image. The resulting indices were applied to all images in the sequence.

Figure 3a is the canonical variate means plot for the training sites using the 2001 image data. It shows that the forest and non-forest training sites are separable, although there are some non-forest sites that are spectrally similar to the forest training sites. This is an indication that the classes can be separated using two indices. In Figure 3a they are separated by the first two canonical vectors, however simpler indices were sought that are more robust through time. A contrast-directed CVA (Campbell and Furby, 1994) was performed on the 2001 image to derive the indices. The indices that resulted from this process were:

- Index 1 = band3 + band5; and
- Index 2 = band4 – band2.

Figure 3b is the plot of the training site means using these indices for the 2001 image data. It shows a majority of easily distinguishable forest and non-forest sites but some overlapping areas, as well. Thresholds that defined the boundary between the certain forest spectral region and the uncertain spectral region were set so that no commission errors were made. Furthermore, additional thresholds were identified that distinguished between the uncertain areas and the certain non-forest 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.

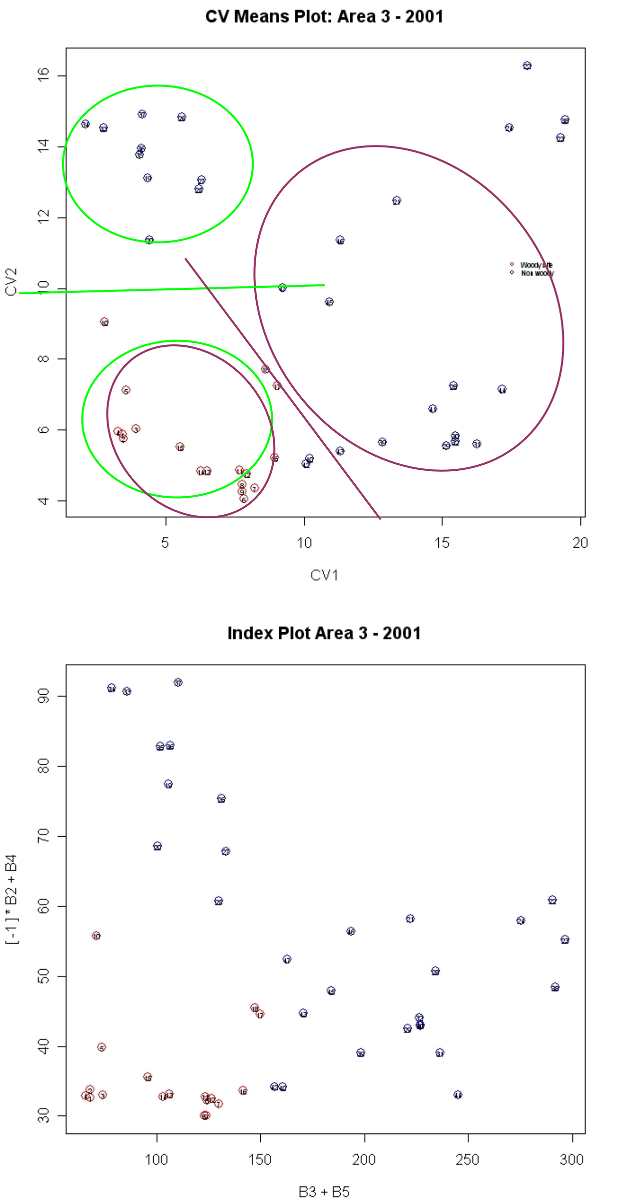

Figure 3. (a) Canonical variate means plot for the training sites using the 2001 data. The groupings of sites, or contrasts, used to derive the indices are shown in green and purple. Forest training sites are shown as red circles and the non-forest as blue circles. (b) Index plot for the training sites using the 2001 data.

The indices and thresholds were used to calculate a probability of forest cover image for each time frame in the following manner:

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

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

3.3.3 Multiple year processing results

The multi-temporal processing was performed using conditional probability networks (CPNs). This approach exploits the observation that many commission errors due to land management practices vary more rapidly compared with forest processes. Temporal rules are used to minimise the probability that such areas are labelled 'forest' in any year. This logic significantly reduced the amount of false change detected when comparing two forest cover maps of any two dates.

The input to CPN are the five forest-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 forest-cover maps. For more details see Caccetta (1997) and Furby (2002). 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. Figure 4c, is the prior probability maps displayed simultaneously for 1994 and 2001. Figure 4d is the modified forest probability maps for 1994 and 2001 estimated by weighing relationships between the CPN variables accordingly to reflect the time interval between image dates. Figure 4e is the modified probability maps with relationships between the CPN variables considered equally 'important', irrespective of the time interval between images.

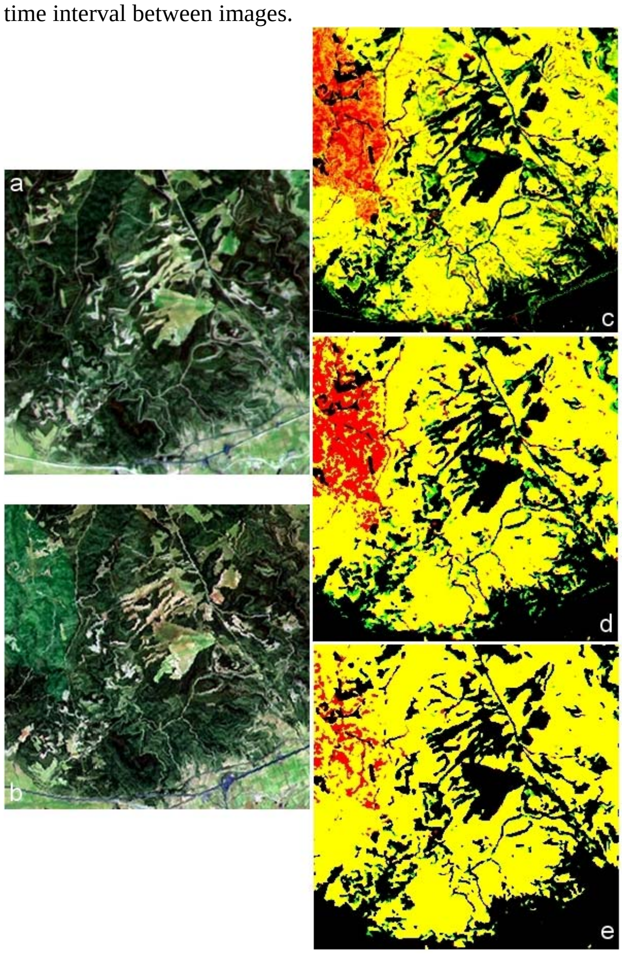

Figure 4. A demonstration of the joint model approach for a sample area. (a) 1994 image. (b) 2001 image. (c) Prior forest probability map. (d) Modified forest probability map with relationships between the CPN variables weighted accordingly to reflect the time interval between image dates. (e) Modified forest 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).

3.3.4 Validation results

The 2001 classified forest/non-forest map was validated using the 1:25000 aerial photographs of the ‘fly-through’ of the Instituto Cartogràfico Valenciano. The overall accuracy of correct predictions was 91%, with 3% and 6% omission and commission errors, respectively.

3.3.5 Density trends

The final step in the process was to look at trends through time in areas with forest cover. Figure 5 shows plots of the first index values through time for some sites in the area of Figure 4 above. Lower values of the index correspond to denser forest cover and higher values to less dense. Areas of increasing forest cover appear to have lower index values in the later years than in the earlier ones. Conversely, areas with decreasing forest 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.

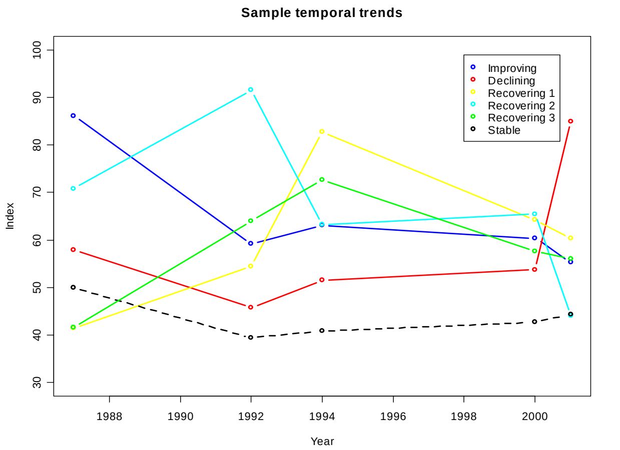

Figure 5. Temporal trends for some sample sites showing areas of stable, improving and declining forest cover as well as areas that have been disturbed and are recovering.

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).

Figure 6 is a sample forest 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 forest cover for that period. Areas shaded in green have been disturbed but are recovering back to the 1987 forest cover level. Yellow and cyan show patterns of disturbance but with partial recovery.

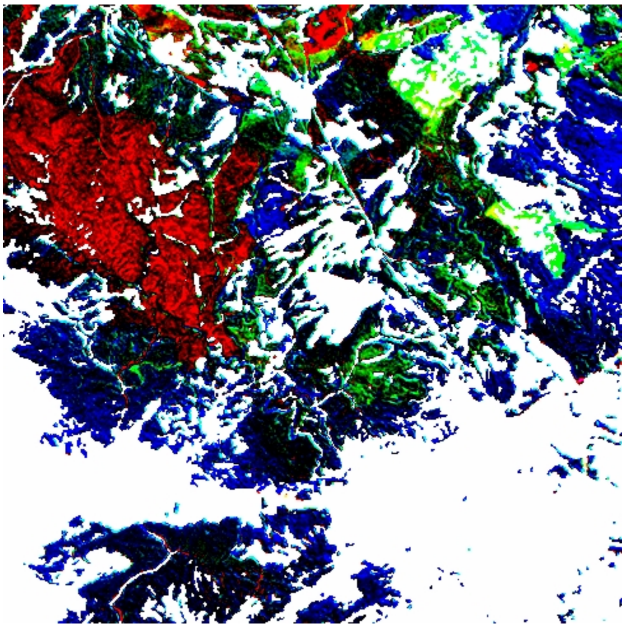

Figure 6. Linear and quadratic temporal trends for a sample area. Shades of blue represent an increasing trend; shades of red a declining trend. Greens are areas that have been disturbed but are recovering whereas mixed colours (yellow and cyan) are areas that have been disturbed and only partially recovered. Stable areas are depicted in black. White are the non-forest areas.

3.4 Discussion

Ortho-rectification plays a critical role in the whole change mapping process. If time-series images are mis-registered, 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).

The calibration process produced good results for all but one image. This means that the number of reliable images left for the multi-temporal processing was reduced even further to four, one of them being the already labelled as ‘problematic’ spring image of 1992. Nevertheless, the CPN computation still produced reasonable modified forest 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 (Figure 4). One consequence of the CPN approach is, though, that long term land cover change (e.g. clearing for agriculture, etc.) is accurately mapped, but 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 forest cover. Depending on the particular question being studied, yearly data should probably be used.

4. CONCLUSIONS

The main conclusions of the trial of the methodology in the Spanish Mediterranean site for mapping LUCC, are:

– DEMs can be used to reduce terrain illumination effects; the better the DEM, the more effects can be removed.
– Existing free ortho-rectified data from various sources are to be used with caution since they could introduce large errors due to mis-registration.
– Large intervals between dates increases the uncertainty in the labelling of the different types of cover. If the temporal gaps are long then some change events may be missed.

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