Mapping Land Use Change using Conditional Probability Networks: a Case Study in the Mediterranean Island of Lesvos

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Abstract – 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 land use/cover mapping and monitoring with remote sensing data. The present study gives an overview of the CSIRO/AGO techniques and demonstrates their applicability in the Mediterranean region using the Greek island of Lesvos as the trial site. For this approach, one starts with a spatially and spectrally consistent set of data. However with limited resources for this project, we used a combination of freely available and purchased Landsat data, spanning 27 years, and focused on the remaining steps of the approach. The utility of NASA's widely used global orthorectified Landsat dataset for LUCC mapping and monitoring was also investigated. Recommendations are made for the successful application of the CSIRO/AGO framework in the Mediterranean region.

Keywords: Land use change, multi-temporal mapping, Landsat, NASA, Mediterranean.

1. INTRODUCTION

Land-use and land-cover change (LUCC) are important to a range of issues central to the study of global environmental change. Changes in the earth's surface hold implications for the radiation balance and energy fluxes, contribute to changes in biogeochemical cycles, alter hydrological cycles, and influence ecological complexity and balances. Through these impacts at all levels LUCC driven by human activity have the potential to affect food security and the sustainability of the agricultural and forest product supply systems (Turner et al., 1995).

The European Union has committed itself to reducing its greenhouse gas (GHG) emissions in order to limit the negative impacts of man-made climate change. As part of signing on the protocol Greece must report on GHG emissions and removals arising from land use and land use change activities. The measurement of these changes is most effectively done using remote sensing technologies. The ability to map LUCC using Landsat data has been examined by many researchers over the last years mainly due to the archives that provide the ability of looking 35 years back in the early 1970s (Symeonakis et al., 2006; Symeonakis et al., 2007).

The Commonwealth Scientific and Industrial Research Organisation (CSIRO), in partnership with the Australian Greenhouse Office (AGO), have devised a series of algorithms and methods which are being used for large-scale land use/cover mapping and monitoring with remote sensing data. The present study gives an overview of the CSIRO/AGO methodology and demonstrates its applicability in the Mediterranean region using the Greek island of Lesvos as the trial site.

Recently, many LUCC studies employ the free NASA archive (Kilic et al., 2006; Symeonakis et al., 2007; Tatem et al., 2006) and the method of post-classification comparison to map land use change. Another objective of the present study was, therefore, to demonstrate that using only the free data one is left with a somewhat different impression of the changes that have taken place and that one should aim for a more suitable sequence of images, in terms of quantity and phenological differentiation of the land use types that are being mapped.

2. METHODOLOGY

The land use mapping methodology performs the following steps:

2.1 Image ortho rectification and calibration

A viewing-geometry approach is first used to ortho-rectify the satellite images, specifically the viewing-geometry and block adjustment model incorporated in the PCI software which implements Toutin's approach (Toutin, 1994) for ortho-rectifying images. The methodology applied is the same as that used by the Australian Greenhouse Office (AGO) to ortho-rectify the image data used for the National Carbon Accounting System (NCAS). A detailed description of how to perform the processing is contained in Furby (2002).

The image data is then calibrated to the same base image. Satellite calibration coefficients are used to calculate top-of-atmosphere reflectances (Wu et al., 2005), then a BRDF model is applied to correct for sun-satellite viewing geometry (Wu et al., 2001) and, finally, invariant targets are used to correct for atmospheric differences between the overpass and base images. This processing adheres to the standards set by the AGO in its Land Cover Change project and is described in detail in Furby (2002).

2.2 Stratification

Typically, within an area that is being mapped, there exist different rainfall zones, different farming practices, different soils and geology, variations in the amount or type of vegetation cover and different landform patterns. Some or all of these may contribute to the types of land cover and the processes driving LUCC. For this reason the image data are better stratified into

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'uniform' regions and the analysis is performed within each region. Typically the results obtained for one region do not extrapolate to other regions and a separate analysis of image values and ground data needs to be performed for each region.

2.3 Training Sites

Ground-truth data showing the location and extent of representative land cover classes is required to train the land cover mapping process. Ideally the ground data comes in the form of air photographs, high-resolution satellite data (e.g. IKONOS, Quickbird) or detailed topographic maps.

2.4 Spectral separability and single-year classifications

Canonical variate analysis (CVA; Campbell and Atchley, 1981) is used to investigate the spectral separability of the training sites and to group the sites into spectral classes that can be adequately discriminated between during the classification process (Campbell and Wallace, 1989).

The single-date classification is an iterative process consisting of the following steps:

1. selection of training sites for the major cover types;
2. canonical variate analyses to assess the separability of the desired classes and to group the sites into spectral classes for the classification;
3. maximum likelihood classification to assign pixels to one of the spectral classes identified; and
4. review of classified image.

The review of the classified image identifies areas where the classification is clearly incorrect. The analyses are repeated, often with additional training sites, aimed specifically at correcting the observed errors. The newly classified image is reviewed and the process is repeated until an acceptable accuracy is reached or until no further improvements are possible.

2.5 Multiple-year processing

Conditional probability networks (CPNs; Kiiveri and Caccetta 1998) are employed to combine the multi-temporal ground cover information from the single-year classifications to produce land use maps. The CPNs provide a statistical framework for combining data, typically with the view to classifying the data. A CPN can be represented by a graph, where the nodes of the graph represent random variables and the edges of the graph represent (conditional) independence assumptions between the variables. Nodes for which we have direct observations are called observed nodes. Nodes for which no direct observations are available, but whose states are inferred from other nodes, are called unobserved nodes and the corresponding variables are called unobserved variables. An example of a network for mapping land use is shown in Figure 1.

The circles and rectangles represent vertices or nodes of the graph. The rectangles represent variables that are observed. The top row of rectangles represents the estimate of the true land use map from the classification of the images for each growing season. The circles represent variables that are not observed, in this case the true land use map at each date. Values for these variables can be inferred from the other variables.

The graph edges or 'arrows' represent relationships between the variables. Observing a particular value for a variable provides some information about all the other variables to which it is connected. The strength of these relationships can also depend on the time interval between image dates. For example, less change would be expected between images one year apart than between images several years apart.

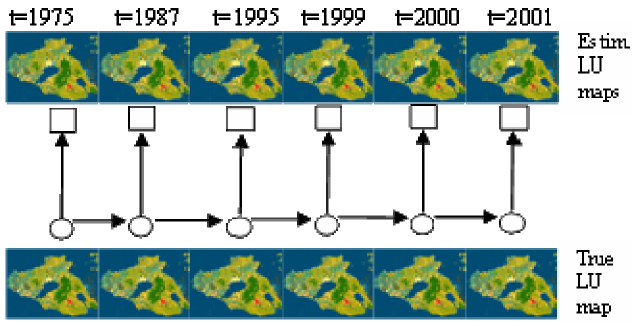


Figure 1. A pictorial representation of the conditional probability network (CPN) applied to land use mapping in the Lesvos study area.

The rules, or the relationships between the variables, are expressed in terms of conditional probability tables. These tables need to be specified or estimated from the data available. Error rates tables link the estimated land use map to the true land use at each date (vertical arrows in Figure 1). Temporal rules link the true land use maps through time (horizontal arrows in Figure 1).

Useful properties of the CPN are that (i) it propagates uncertainties in inputs and calculates uncertainties in outputs; (ii) it produces hard and soft maps; (iii) it handles missing data by using all available information to make predictions; and (iv) there exist well-developed statistical tools for parameter estimation (Caccetta et al., 2000).

2.6 Land use change mapping

To create land use change maps, the individual classifications produced from the CPN are compared. A manual attribution process is applied by the AGO to separate directly human-induced land use change from seasonal fluctuations in land cover.

2.7 Accuracy assessment

Accuracy assessment is a three stage process: (i) image pre-processing accuracy; (ii) land use classification accuracy; and (iii) land use change accuracy.

3. PILOT STUDY

3.1 The area

Lesvos is situated in the eastern Mediterranean Sea and is one of the largest Aegean islands of Greece (Figure 2). It covers an area of approximately 163000ha and has a maximum altitude of 947m. The climate is characterised by strong seasonal and spatial variations of rainfall and high oscillations between minimum and maximum daily temperatures, typical of the Mediterranean region (Kosmas et al., 2000).

Figure 2. Location of Lesvos (in rectangle) in the Aegean Sea.

3.2 The data

Six MSS, TM and ETM+ images were used spanning 27 years from 1975 till 2001. Budget limitations on the one hand and availability of cloud-free data on the other led to the following choice of images: 16 July 1975 (MSS, NASA); 11 May 1987 (TM, NASA); 4 July 1995 (TM, Eurimage); 28 May 1999 (TM, Eurimage); 7 June 2000 (ETM, NASA); and 26 June 2001 (ETM, Joint Research Centre).

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 first stage of the trial, (training and) land use validation data came in the form of a Quickbird image of 2001. Therefore, it was only the 2001 land use map that was validated appropriately. Although some change between the 1999 and 2000 dates must have taken place, the land use maps produced from those images were also validated against the Quickbird image in the absence of a more reliable source for validation.

3.3 Preliminary results

Depending on the separability of the land cover classes in each date image, 12 to 17 classes of land cover were mapped. Some of the land cover classes were spectrally very similar, which makes them difficult to map, for example Mediterranean maquis vs. olive groves, or bare vs. urban areas. An example of a canonical variate means plot for training sites from all 14 classes mapped from the 1999 image is shown in Figure 3.

The above classes were grouped to form the final 7 land use classes, namely: (i) bare; (ii) urban; (iii) scrubs (i.e. garrigue) and Mediterranean maquis; (iv) olive groves; (v) other crops (irrigated and non-irrigated); (vi) pine and deciduous forests; and (vii) water (including sea water and saltern).

Due to the lack of validation data no accuracy assessment was carried out for the first three dates (1975, 1987 and 1995). In the future, the 1975 classification will be validated against aerial photos of the 1960s. It is questionable whether appropriate data exist to validate the 1987 and 1995 LUC maps. At this preliminary stage of the project, no expert 'hard' rules were applied either since, the objective was not to estimate percentages of change per class but, to examine how different the results can be when one uses a subset (3 dates) of the available data (6 dates).

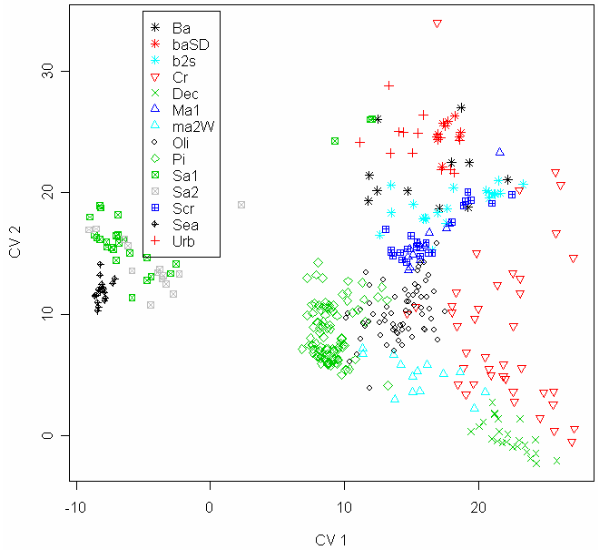
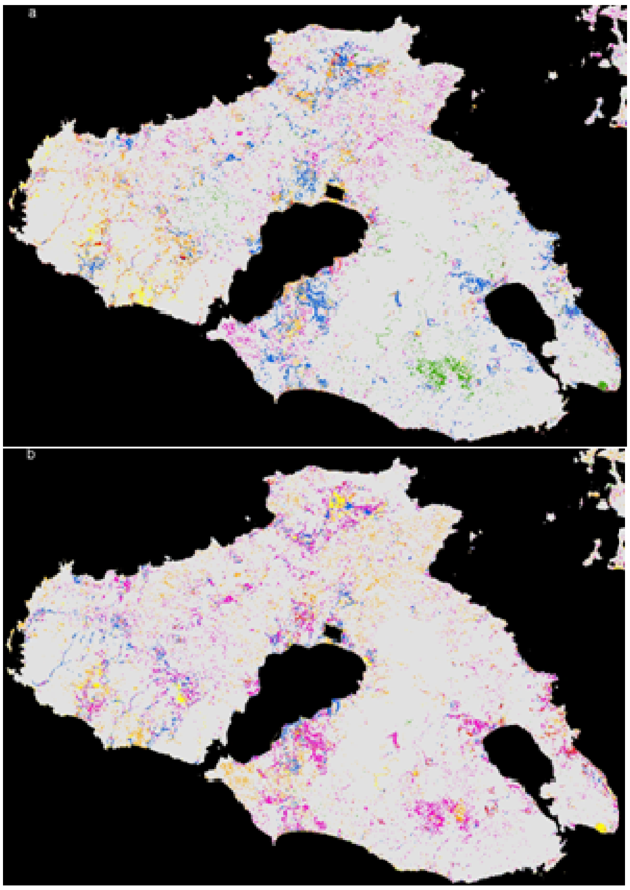


Figure 3. Canonical variate means plot for all training sites using the 1999 data. The spectral groupings identified from this image are shown.

The change maps produced from the CPN using all 6 dates and the subsequent comparison of the first and last dates are shown in Figure 4a and 4b. Figure 4c is the equivalent of 4a produced by employing only the free NASA data (1975, 1987, 2000).



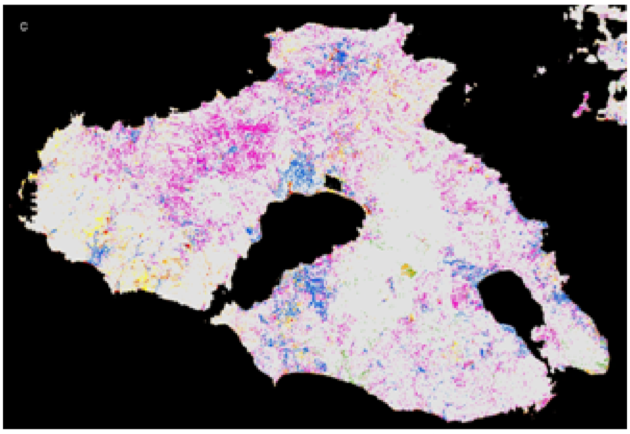


Figure 4. Land use change maps. (a,b) 1975 to 2000, estimated using all 6 dates in the Conditional Probability Network. (a) 'change-from-class'; (b) 'change-to-class'; Yellow = Bare, Red = Urban, Orange = Scrub and Maquis, Magenta = Olives, Green = Forest, Cyan = Water; (c) 'Change-from-class', 1975 to 2000, estimated using only the 3 free NASA images.

4. DISCUSSION

Under the Kyoto Protocol Greece has agreed to reduce its carbon dioxide emissions by 8% from 1990 levels between 2008 and 2012. So far, it has failed to comply with its commitments and faces a bill of at least 225 million euros by 2010 (Kathimerini, 2006). An important first step that needs to be carried out is the accurate mapping of land use and land cover change. The pilot study in the island of Lesvos has implemented a processing stream for production of land use maps based on single date Landsat imagery, and land use change maps derived from them. Dependent on suitable historical imagery, operational implementation at national scale should be feasible for all the steps from basic image processing through to classification, map production and validation.

An important finding from the preliminary results of this study is also that, using the free NASA data only produces spatially different results from using, for example, twice as many dates. This issue needs to be treated with caution by the scientific community especially when quantitative analyses of the land use changes are sought. It is highly recommended that a fuller set of Landsat data, optimally on a yearly basis, is employed for accurately mapping land use and land use change.

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