

REMOTE SENSING ANALYSIS OF LAND COVER CHANGE

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ABSTRACT:

In Australia, remotely sensed Landsat data is routinely used for mapping and monitoring changes in the extent of woody perennial vegetation. Time series remotely sensed satellite imagery and ground information is used to form multi-temporal classifications of presence/absence of woody cover. Two broad-scale operational land cover change and monitoring projects are based on a series of algorithms and methods developed by the CSIRO. This paper gives an overview of these remote sensing techniques and demonstrates their use in China using a trial site within the Fujian province.

1. INTRODUCTION

In Australia, broad-scale operational programs for mapping and monitoring the extent of woody perennial vegetation are based on time series of Landsat imagery. One is the National Carbon Accounting System (NCAS) Landcover Change Project which covers the entire Australian continent (Furby, 2002). Another is the Land Monitor Project which covers 24 million hectares in Western Australia (Caccetta *et al.*, 2000). These operational programs are based on series of algorithms and methods developed by the CSIRO. These methods have recently been tested in the Fujian province, China, as a trial of their applicability in a different environment. This paper provides an overview of the remote sensing techniques and of the results of the Fujian province trial.

2. METHODOLOGY

In the NCAS and Land Monitor projects, long-term sequences of ortho-rectified and calibrated Landsat satellite data are processed to provide observations relating to land cover and change. Discriminant analysis techniques are applied to quantify spectral separation of classes of interest (in this case woody vs non-woody). Samples of woody and non-woody training and validation data are obtained from interpretation of high-resolution aerial/satellite imagery and ground truth. Results are used to develop classifiers which are applied to the sequence of individual images. Finally, these classifications are combined using spatial/temporal models to reduce errors in maps of forest cover and change. Results are used in Australia's national carbon accounting and for resource management and planning.

The image processing steps are as follows:

1. selection of Landsat scenes and registration of time series Landsat data;
2. calibration of Landsat data to a common reference;
3. processing of the calibrated data to remove 'corrupted' data, which include dropouts, data affected by fire, smoke and cloud;
4. terrain illumination correction of the calibrated data to adjust for differential viewing geometry;

5. stratification of the data into 'zones', where landcover 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. Greater classification accuracies are obtained after applying a joint model.

Steps 3 and 5 are self explanatory. The other processing steps, as implemented in the CSIRO methods, are briefly described in the following subsections.

2.1 Image Rectification

The two steps in establishing a rectified sequence of Landsat imagery are: 1) establish a common ortho-rectified base mosaic of Landsat data; and 2) ortho-rectify temporal sequences of images to the common base.

Accurate ortho-rectification was achieved using a rigorous earth-orbital model. PCI OrthoEngine software was used for this purpose. Once the ortho-rectified base was established, ground control points (GCP) were automatically matched using a cross-correlation technique. This approach improves efficiency and accuracy of the results. For quality assurance, visual inspection and numerical summaries based on cross-correlation feature matching are used to assess the accuracy of ortho-rectification of the time series images.

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: 1) Top-Of-Atmosphere (TOA) reflectance calibration (also called sun angle and distance correction); 2) Bi-directional Reflectance Distribution Function (BRDF) calibration (Danaher *et al.*, 2001); and 3) terrain illumination correction. Each step is briefly described in the following subsections.

2.2.1 Top-Of-Atmosphere (TOA) reflectance calibration:

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).

2.2.2 BRDF Calibration:

Angular effects across the Landsat image result in BRDF effects which are relatively small, but significant in the context of broad-scale monitoring. The BRDF correction is a simple linear function of scan angle which is applied to each band. A two-kernel empirical BRDF model was used to correct the remaining scene-to-scene differences. Simple variations of Walthall's model, as described by Danaher *et al.* (2001), were used in the BRDF calibration approach. The model is a three-parameter model (see Equation 3 in (Danaher *et al.*, 2001)), where the three parameters were calculated by solving equations based on the image overlap areas, and the same parameters were applied to all scenes (Wu *et al.*, 2001).

2.2.3 Terrain Illumination Correction:

This third step is required where there are significant terrain illumination effects, resulting in bright and dark sides of hills and mountains. This is particularly important for time series imagery where terrain effects 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. A high-resolution digital elevation model (DEM) is required to achieve adequate removal of terrain effects.

2.3 Woody Classification

Canonical Variate Analysis (CVA) (Campbell and Atchley, 1981, McKay and Campbell, 1982a, 1982b) and related procedures are used to define optimal discriminant indices for each zone. The index-threshold classification approach (Furby, 2002) is used to produce the forest or woody probability maps for each date within the sequence.

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, we use joint models which incorporate error rates of the initial classifications as well as temporal and spatial rules.

The sequence of cover class probabilities from all dates is analysed using a joint model approach (Caccetta, 1997, Kiiveri and Caccetta, 1998). This approach uses the probabilities from neighbouring dates to modify the probabilities of each pixel. The effect of the method is that it 'smoothes out' sudden changes (e.g. from cultivation), and reduces uncertainty and errors in the individual dates. The result is a series of modified probability maps for each date (the forest probability maps before applying the joint model are called 'the prior forest probability map' while the probability map produced after applying the joint model is called 'the modified forest probability map').

2.5 Landcover Change Maps

From the modified probability maps produced from the joint

model, 'yes/no' woody masks for each date were formed, and then compared to form change maps. The land cover change maps were provided for further statistical analysis of changes and for carbon modelling.

3. FUJIAN TRIAL

As a part of an Australia-China project organised by the Australian Greenhouse Office (AGO) and the Chinese Academy of Forestry, a trial using these methods for monitoring forest change in China was performed for a test area in the Fujian province, China. The aim of the trial was to assess the application of the methods in China. This section outlines the data processing and results for land cover change in the Fujian trial. Some issues are discussed and some recommendations are made.

3.1 The Area and Satellite Image Data

The trial region in the Fujian province, a single Landsat scene, is shown as the yellow rectangular region in Figure 1. A time-series of eight Landsat TM images spanning 16 years were carefully chosen for the Fujian trial region — 1988, 1989, 1992, 1995, 1998, 2001, 2003 and 2004. The scene seasons are around summer and autumn (from September to November). These scenes were purchased from the Remote Sensing Ground Station (RSGS), Beijing, China.



Figure 1. Coverage of Fujian trial region, China (Map source: <http://encarta.msn.com>).

3.2 Digital Elevation Model (DEM)

Since a high-resolution DEM (25 metres, the same as the ortho-rectified images' pixel size) was not available for the project, the SRTM DEM (Shuttle Radar Topography Mission, U.S. Geological Survey) of the trial region was used instead. A sun-shaded sub-region of the SRTM DEM is shown in Figure 2(c).

Some pre-processing steps were applied to the SRTM DEM in order to meet our purposes:

1. the projection was converted to UTM Projection: NUTM 50, Datum: WGS84, the same as the Landsat TM images,
2. DEM grid cells were resampled from 90m to 25m using the bilinear interpolation method, and
3. there are some empty cells in the SRTM DEM caused by terrain effects; these were assigned values based on interpolating the elevation values from neighbouring cells.

3.3 Ground Control Points (GCP)

An ortho-rectified Landsat 7 ETM+ scene (21 October, 2001) obtained from the Global Land Cover Facility — GLCF (<http://glcf.umd.edu/index.shtml>) was chosen as the rectification reference for the Fujian trial. Ninety-nine GCPs were then collected from the reference image. The GLCF ortho-rectified scene itself was not used in subsequent analysis as it was generated using the nearest-neighbour interpolation method (alternative resampling methods such as the 16-point Kaiser-Damped Sinc convolution techniques are recommended).

3.4 Woody Sites - Ground Information

Usually ground data, high-resolution aerial/satellite images and local knowledge are required to identify tree types on images inside the trial region. Dr Hong Yan from the Chinese Academy of Forestry assisted in identifying the tree types on the 2001 image. Some Chinese Fir sample sites were also provided by Dr Trevor Booth and Dr Keryn Paul from CSIRO Forestry and Forest Products, and their colleagues in the Chinese Academy of Forestry.

3.5 Methodology

The steps used to produce the series of vegetation maps were described in the previous section. A few comments related to Fujian Landsat data processing:

1. The SRTM DEM was used for the Fujian Landsat ortho-rectification and terrain illumination correction. Ortho-rectified sub-region images are shown in Figure 2(a) (2001) and Figure 2(b) (2004).
2. The CVA analysis from the woody/non-woody samples results in using two indices: $-3 \cdot \text{band3} + \text{band4}$ (index 1) and $-3 \cdot \text{band3} - \text{band4} + \text{band5}$ (index 2). Thresholds are used to divide the index scores into values that are certain woody (100% probability), certain non-woody (0% probability), and uncertain cover in between (0-100% probability) scaled linearly with distance relative to the thresholds. The threshold values for these indices are known to vary spatially. A threshold matching technique was applied to automatically adjust these thresholds for other time slice maps based on the base map (year 2001 in this case). This automatic matching improves consistency and saves labour intensive work.

3.6 Results from the Fujian Trial

Ortho-rectification plays a critical role in the whole processing. If time series images are mis-registered, the same pixel on another year's image will be shifted and it will cause severe problems for tracking land cover change through time. The average GCP residuals from earth-orbital model fitting for all eight time series images are less than a third of the pixel size (<8m).

Terrain illumination correction has removed the large terrain effects as can be seen from the images shown in Figure 2(d) and Figure 2(e). However, many finer terrain effects, especially in local valleys on hillsides, are still visible and remain on the image after applying terrain-correction (Figure 3). This is due to the coarse resolution of the SRTM DEM. A high-resolution DEM will improve the correction and the results in regions with undulating terrain.

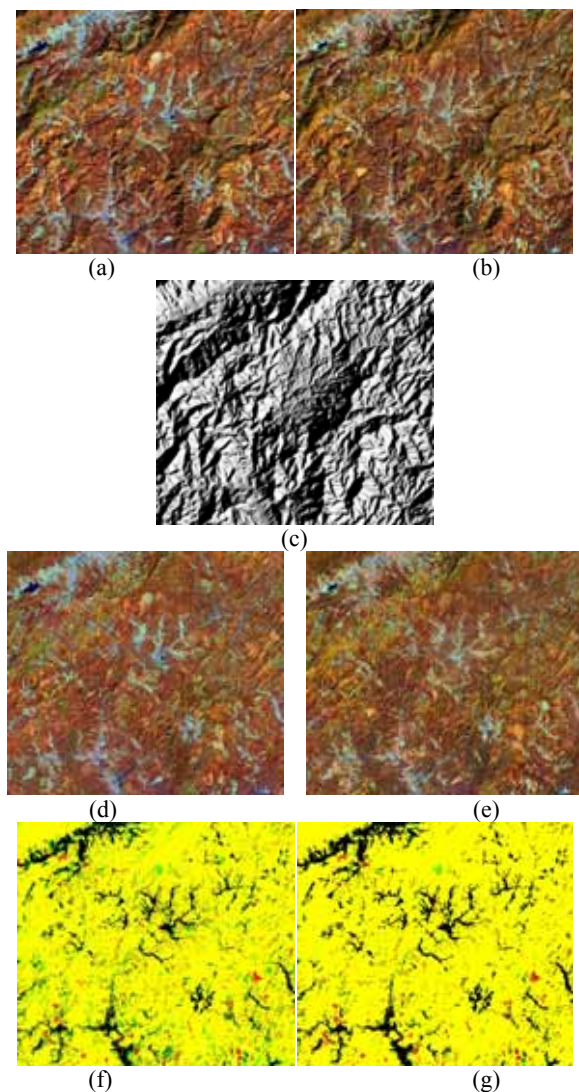
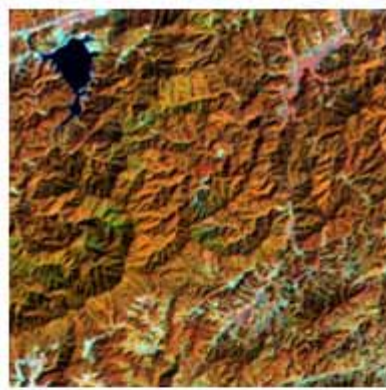
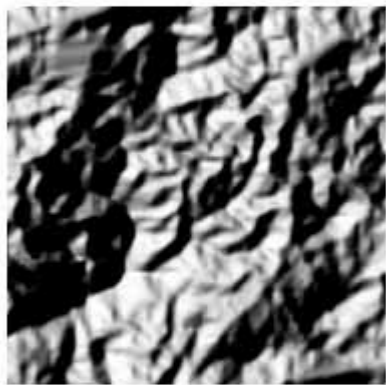


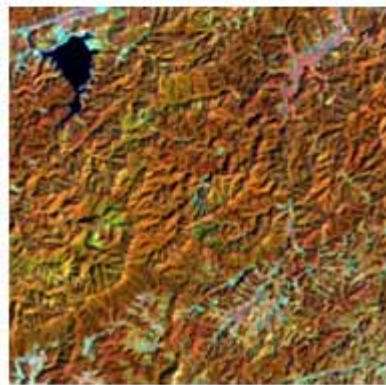
Figure 2. A sample area which demonstrates reasonably good results in the trial region. (a) and (b) show the images before applying terrain-correction ((a) is year 2001 image and (b) is year 2004 image). (c) shows the SRTM DEM (sun-shaded) corresponding to the same area. (d) and (e) show images after applying terrain-correction. (f) shows the prior forest probability maps (2001 in red and 2004 in green) and (g) shows the modified forest probability maps (2001 in red and 2004 in green). Most of the 'false change' in (f) has been removed by the time-series processing.



(a)



(b)



(c)

Figure 3. A sample area which illustrates the SRTM DEM (sun-shaded) with 90m resolution is inadequate for undulating or fragmented terrain such as this area. Some shadows/terrain effects are still visible and remain on the image after applying terrain-correction: (a) the un-corrected image; (b) the corresponding SRTM DEM; and (c) the corrected image.

The CVA analysis ordination plot for the 2001 image (Figure 4) clearly shows that woody/non-woody cover is well discriminated in the Fujian trial region using the Landsat TM data. The prior probability map obtained for each year shows the indices derived from CVA analysis incorporated with the index-threshold approach works very well for the time series images (Figure 2(f)).

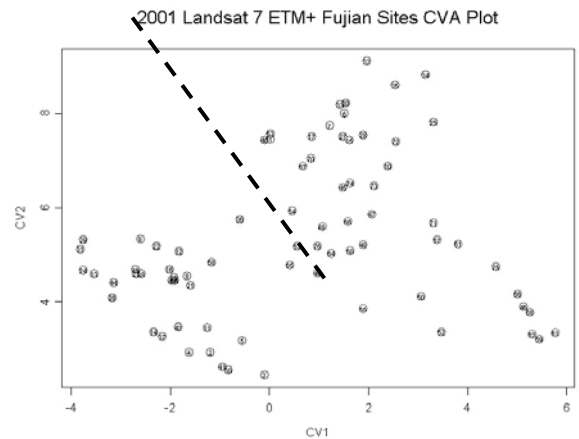


Figure 4. Ordination plot from CVA analysis for 2001 image using woody/non-woody samples. These dots in the bottom-left part are the woody samples while the rest of the samples are of non-woody cover types. This plot clearly shows that woody and non-woody cover can be easily discriminated using spectral indices

The joint model computation produces reasonable modified forest probability maps from 1988 to 2004. The joint model smoothed individual-date classification error and even removed some of the remaining terrain-induced error effects on the prior probability maps (Figure 2(g)). One consequence of the joint model approach is that long term land cover change (such as clearing of forest for agriculture) is more accurately mapped, but ‘transient’ land cover change which only appears in one image date can be ‘over-smoothed’. For example, the information on clearing of forest which then re-grows before the next image may be lost in the joint model processing.

3.7 Accuracy and Limitations

The typical results (e.g. Figure 2) obtained from the Fujian trial clearly demonstrate that our remote sensing techniques work well in the trial area, using almost identical procedures to those which are applied successfully in Australia. However, similar to the situation in Australia, a few issues remain when applying our remote sensing techniques.

The land cover change maps are derived from reflectance signals detected by Landsat TM, and depend on a contrast between woody and other cover types (soil, crops, bare rocks etc). The thresholds for classification of woody cover have been derived from interpretation and comparison/matching with the base map (year 2001).

This classification as woody relies on the spectral contrasts of cover types resulting from physical differences on the ground, and effectively requires a certain density of vegetation. Hence thin, scattered vegetation with a high proportion of soil background may be omitted. In particular, bare or very thin areas within woody vegetation will not be classified as ‘woody cover’. Common examples are tracks, rocks, fire-scars, and salt-affected vegetation. Hence the areas mapped as woody at particular dates will not necessarily correspond to administrative definitions of reserves etc. Certain dense but highly reflective vegetation types may also be omitted, but no cases of such omissions are known.

There is a time lag in detection of re-vegetated areas, which varies with region and vegetation type. Re-vegetated areas

will not be mapped until the vegetation achieves a sufficient density. Hence some recent, slow-growing, or sparse re-vegetated areas will not be detected until they are present for several image dates.

Errors of commission may occur when other land covers give a similar spectral response to woody cover. The temporal smoothing of the joint model removes most of the transient cultivation effects that might cause these errors. However, there are cases where errors of commission may remain after the joint model processing. Examples include cleared areas with persistently dark soil, and also lake fringes and normally dry lake surfaces where changes in water level have dramatic effects on the cover and reflectance. Errors that are incurred in these areas may result in incorrect mapping of change in lake edge vegetation. However, these errors have not been removed by manual digitising as some may be real land cover change.

Various regions show reasonable results were produced from the joint model even when some terrain effects still remain on the prior forest probability maps, while the results also show the vegetation re-growth issue mentioned in the above paragraphs.

Figure 5 presents one type of visual display of land cover change in the Fujian region formed from three dates: 1998, 2001 and 2004 in blue, red and green, respectively. Landsat TM band 5 was used for these years. Areas displayed in shades of grey have undergone little or no change, whereas brightly coloured areas have changed. The colours give an indication of the timing of the change.

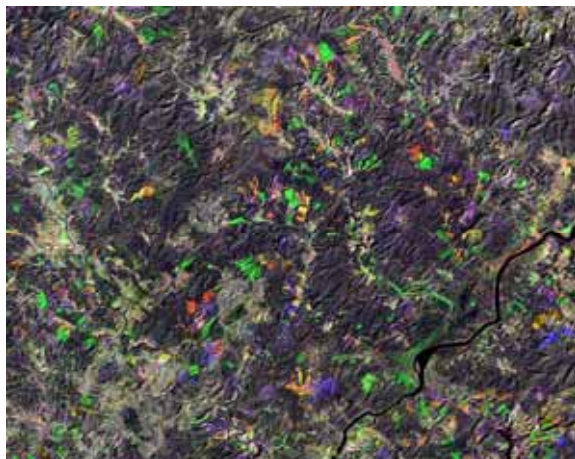


Figure 5. This image illustrates typical land cover changes in the Fujian region from three dates: 1998, 2001 and 2004 in blue, red and green, respectively. Landsat TM band 5 was used for these years.

3.8 Conclusions and Recommendations

The results obtained from the Fujian trial clearly demonstrate that our remote sensing techniques work reasonably well in the Fujian trial region. A few comments when our processing procedure was applied to the Fujian trial:

1. Default BRDF kernel coefficients were used to calibrate all images because of the lack of enough images to estimate the BRDF kernel coefficients. It is desirable to use locally estimated BRDF kernel coefficients if there are enough overlapping images.

2. The SRTM DEM is sufficient for performing ortho-rectification but the resolution is not high enough to achieve ideal terrain illumination correction.
3. The joint model performed well in removing single-date classification error and some of the remaining terrain effects from the prior probability maps.
4. The joint model applied in this study 'over-smoothed' in areas of transient land cover change, such as forest areas that were cleared then re-grew or were replanted before the next image date.

Some recommendations:

1. In areas affected by terrain, a high-resolution DEM is required to ensure images are properly ortho-rectified and terrain corrected.
2. Advanced models such as a second-order joint model may be required to better track the changes through time.
3. More frequent time slices may be required to improve the results for detection of 'transient' land cover change. One-year intervals between images may be a solution.

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