Monitoring land cover change in RUFAs: A novel approach based on the VIS model and change indicators

Xiaodong Mu[1], Huiping Liu[2]

[1]School of Geography, Beijing Normal University, No. 19, XinJieKouWai St., HaiDian District, Beijing 100875, P. R. China
Telephone: (+86-138-1167-6624)
Email: muxiaodong@mail.bnu.edu.cn

[2] School of Geography, Beijing Normal University, No. 19, XinJieKouWai St., HaiDian District, Beijing 100875, P. R. China
Telephone: (+86-137-0130-8210)
Email: hpliu@bnu.edu.cn

1. Introduction

Change detection is the process of identifying differences in the state of an object or phenomenon by observing it at different times(Singh 1989). Timely and accurate change detection of Earth’s surface features provides the foundation for better understanding relationships and interactions between human and natural phenomena to better manage and use resources(Lu et al. 2004). Satellite sensors are well suited to monitoring changes on the Earth's surface through provision of consistent and repeatable measurements at a spatial scale appropriate for many processes causing change on the land surface including natural and anthropogenic disturbance, climate change and urbanization(Kennedy, Cohen and Schroeder 2007).

The development of satellite-based change detection methods has been an area of active investigation for more than 25 years (Fraser, Olthof and Pouliot 2009) and numerous techniques have been proposed and developed (Lu et al. 2004, Chen et al. 2012). Depending on the different emphases, they can be summarized as different types (Lunetta et al. 2006, Desclee, Bogaert and Defourny 2006, Fraser et al. 2009). There are a wide range of change detection applications, such as land-use and land-cover change(Lasanta and Vicente-Serrano 2012, Lambin and Strahler 1994, Le Hegarat-Mascle, Ottle and Guerin 2005), forest or vegetation change(Gomez, White and Wulder 2011, Kennedy, Yang and Cohen 2010, Wilson and Sader 2002, Jin and Sader 2005), urban change(Ridd and Liu 1998, Zhang et al. 2002, Liu and Lathrop 2002), wetland change(Dronova, Gong and Wang 2011) and so on.

1.1 Change detection method

In general, change detection methods can be grouped in to two types, (1) those detecting binary change/no-change information; and (2) those detecting detailed ‘from–to’ change(Lu et al. 2004).

Traditional binary change detection is based on a simple calibration which works on one resultant change image (i.e., a difference image) and a few discrete thresholds. It has two main limitations, 1) the accuracy is based on the selection of the threshold; 2) it can’t provide detailed “from-to” change information(Im, Jensen and Hodgson 2008). Post-classification is the most common method to obtain “from-to” change information. Originally, the post-classification approach was considered to be the most reliable approach and was used to evaluate emerging methods. However, Factors that limit the application of post-classification change detection techniques can include cost, consistency, and error propagation(Lunetta et al. 2006). Moreover, change vector analysis (CVA) is a valuable change detection method which determines the change information by the angle of change (vector direction) and the magnitude of change. However, how to reasonably determine thresholds of change magnitude and change direction is a bottleneck to its proper application(Chen et al. 2003), and clustering techniques require a further manual post-processing for associating the identified clusters with changed or unchanged labels, which increases the level of required supervision and decreases the level of automation(Bovolo, Bruzzone and Marconcini 2008).

So far, lots of novel change detection methods have been proposed to overcomes aforementioned drawbacks, such as change detection based on clustering of feature space(Kontoes 2008), change detection incorporating spatial-temporal contextual information(Liu et al. 2008, Liu and Cai 2011, Boucher, Seto and Journel 2006), change detection using change index(Wang et al. 2009, Le Hegarat-Mascle and Seltz 2004), object-based change detection(Chen et al. 2012, Bontemps et al. 2008), and automated change detection method(Salmon et al. 2011, Bovolo et al. 2008).

1.2 Assessment of method

Lu et al. (2004) indicate that a good change detection research should provide the following information: (1) area change and change rate; (2) spatial distribution of changed types; (3) change trajectories of land-cover types; and (4) accuracy assessment of change detection results.

Obviously the first and second are the basic requirements for a change detection method. The third and the fourth are the most critical standards for assessing a change detection method, especially for change detection in time series of satellite imagery. Most studies agree that the importance of change trajectories which can provide important information on landscape dynamics that are critical to our understanding of complex human–environment adaptive systems. However, few studies have paid attention to the method of construction and analysis of change trajectories. Meanwhile, accuracy assessment is an integral component of any change detection study.

van Oort (2007) points out there are three matrices in assessment of change detection accuracy, (1) single date error matrices and (2) binary change/no change error matrices are commonly reported, (3) transition error matrix is less common form of reporting. He discusses the relation between these matrices in his study. Liu and Cai (2011) consider that a rigorous accuracy assessment should also follow an error matrix–based approach similar to the one used for land-cover classification, but constructing a change detection error matrix is generally challenging due to the difficulties in collecting sufficient testing samples of land-cover changes over time, and they propose two approach to assess the accuracy of land-cover change trajectories. One of the approaches is based on the rationality analysis of reconstructed land-cover change trajectories. Liu and Zhou (2004) first present the rule-based rationality analysis method for accuracy assessment of multi-temporal images change detection, although the rules for the rationality analysis are somewhat ideal.

1.3 Research goal

LUCC is an important field in global environmental change research and impacts on the environment and associated ecosystems at different scales (Chen et al. 2003, Lambin et al. 2001). Detecting LULC changes in rural–urban fringe areas (RUFAs) is difficult because the land covers are often heterogeneous and fragmental in nature, but essential for land-use planning and management during the process of urbanization in China (He et al. 2011).

This research aims to develop a novel method to monitor the land cover change in RUFAs, Chaoyang District, Beijing, based on vegetation-impervious surface-soil (VIS) model and change indictors, using time series Landsat imagery from 1999 to 2011. The land-cover types can be categorized as four main types according to VIS model in RUFAs(Qiao et al. 2010), which are vegetation, impervious surface, soil and water. The research consists of the following parts: (1) establishment of the indictors which are capable of indicating land cover change, (2) bi-temporal change detection method, (3) method validation in multi-temporal images, (4) change detection accuracy assessment based on rationality of change trajectories. Compared with the existing studies, the method in this study has several advantages: (1) this method was sought to be efficient and easy-to-use; (2) there is no need to seek any thresholds for obtaining change/no-change information; (3) according to the patterns of change indicators, the level of required supervision decreases while labels the “from-to” change information; (4) the rationality rules for accuracy assessment are more consistent with the actual changes.

2. Equations, Figures and Tables

Equations used in this study:

$$\begin{aligned}\Delta NDVI &= NDVI_2 - NDVI_1 \\ NDVI &= (NIR - R)/(NIR + R)\end{aligned} \tag{1}$$

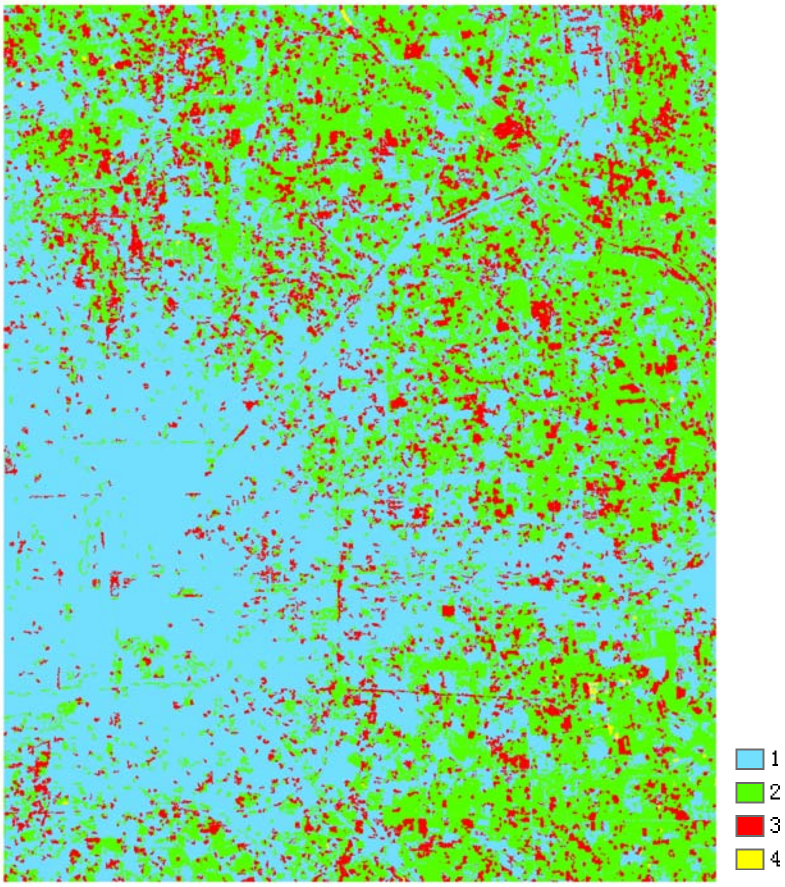
$$\begin{aligned}\Delta NDBI &= NDBI_2 - NDBI_1 \\ NDBI &= (MIR - NIR)/(MIR + NIR)\end{aligned} \tag{2}$$

$$\begin{aligned}\Delta NDWI &= NDWI_2 - NDWI_1 \\ &(Green - NIR)/(Green + NIR)\end{aligned} \tag{3}$$

$$CM = \sqrt{(b_{21} - b_{11})^2 + (b_{22} - b_{12})^2 + \ldots + (b_{2n} - b_{1n})^2} \tag{4}$$

Date	Sensor
07/ 01/1999	ETM+
05 /19 2001	ETM+
09/08/ 2004	TM
09/06/ 2006	TM
09/22/ 2009	TM
08/08/2010	TM
05/08/ 2011	TM

Table 1. Dates of Landsat 5-TM and Landsat 7-ETM+ images used in this study.



1. No-change 2.Reasonable change 3.Unreasonable change 4.Uncertain change

Figure 1. The result of accuracy assessment of change detection.

Type	Pixels	%
No-change	464356	
Reasonable change	303525	73.6%
Unreasonable change	107686	26.1%
Uncertain change	1153	0.3%

Table 2. Statistics of accuracy assessment.

3. Acknowledgements

This research was supported by National Key Technology Research and Development Program (2008BAK49B04 and 2008BAK49B07-3), National Natural Science Foundation of China (40671127) and National China Next General Internet Program (CNGI–09–01–07).

4. References

Bontemps, S., P. Bogaert, N. Titeux & P. Defourny (2008) An object-based change detection method accounting for temporal dependences in time series with medium to coarse spatial resolution. *Remote Sensing of Environment,* 112**,** 3181-3191.

Boucher, A., K. C. Seto & A. G. Journel (2006) A novel method for mapping land cover changes: Incorporating time and space with geostatistics. *Ieee Transactions on Geoscience and Remote Sensing,* 44**,** 3427-3435.

Bovolo, F., L. Bruzzone & M. Marconcini (2008) A novel approach to unsupervised change detection based on a semisupervised SVM and a similarity measure. *Ieee Transactions on Geoscience and Remote Sensing,* 46**,** 2070-2082.

Chen, G., G. J. Hay, L. M. T. Carvalho & M. A. Wulder (2012) Object-based change detection. *International Journal of Remote Sensing,* 33**,** 4434-4457.

Chen, J., P. Gong, C. Y. He, R. L. Pu & P. J. Shi (2003) Land-use/land-cover change detection using improved change-vector analysis. *Photogrammetric Engineering and Remote Sensing,* 69**,** 369-379.

Desclee, B., P. Bogaert & P. Defourny (2006) Forest change detection by statistical object-based method. *Remote Sensing of Environment,* 102**,** 1-11.

Dronova, I., P. Gong & L. Wang (2011) Object-based analysis and change detection of major wetland cover types and their classification uncertainty during the low water period at Poyang Lake, China. *Remote Sensing of Environment,* 115**,** 3220-3236.

Fraser, R. H., I. Olthof & D. Pouliot (2009) Monitoring land cover change and ecological integrity in Canada's national parks. *Remote Sensing of Environment,* 113**,** 1397-1409.

Gomez, C., J. C. White & M. A. Wulder (2011) Characterizing the state and processes of change in a dynamic forest environment using hierarchical spatio-temporal segmentation. *Remote Sensing of Environment,* 115**,** 1665-1679.

He, C. Y., A. N. Wei, P. J. Shi, Q. F. Zhang & Y. Y. Zhao (2011) Detecting land-use/land-cover change in rural-urban fringe areas using extended change-vector analysis. *International Journal of Applied Earth Observation and Geoinformation,* 13**,** 572-585.

Im, J. H., J. R. Jensen & M. E. Hodgson (2008) Optimizing the binary discriminant function in change detection applications. *Remote Sensing of Environment,* 112**,** 2761-2776.

Jin, S. M. & S. A. Sader (2005) MODIS time-series imagery for forest disturbance detection and quantification of patch size effects. *Remote Sensing of Environment,* 99**,** 462-470.

Kennedy, R. E., W. B. Cohen & T. A. Schroeder (2007) Trajectory-based change detection for automated characterization of forest disturbance dynamics. *Remote Sensing of Environment,* 110**,** 370-386.

Kennedy, R. E., Z. G. Yang & W. B. Cohen (2010) Detecting trends in forest disturbance and recovery using yearly Landsat time series: 1. LandTrendr - Temporal segmentation algorithms. *Remote Sensing of Environment,* 114**,** 2897-2910.

Kontoes, C. C. (2008) Operational land cover change detection using change vector analysis. *International Journal of Remote Sensing,* 29**,** 4757-4779.

Lambin, E. F. & A. H. Strahler (1994) Indicators of Land-Cover Change for Change-Vector Analysis in Multitemporal Space at Coarse Spatial Scales. *International Journal of Remote Sensing,* 15**,** 2099-2119.

Lambin, E. F., B. L. Turner, H. J. Geist, S. B. Agbola, A. Angelsen, J. W. Bruce, O. T. Coomes, R. Dirzo, G. Fischer, C. Folke, P. S. George, K. Homewood, J.

Imbernon, R. Leemans, X. B. Li, E. F. Moran, M. Mortimore, P. S. Ramakrishnan, J. F. Richards, H. Skanes, W. Steffen, G. D. Stone, U. Svedin, T. A. Veldkamp, C. Vogel & J. C. Xu (2001) The causes of land-use and land-cover change: moving beyond the myths. *Global Environmental Change-Human and Policy Dimensions,* 11**,** 261-269.

Lasanta, T. & S. M. Vicente-Serrano (2012) Complex land cover change processes in semiarid Mediterranean regions: An approach using Landsat images in northeast Spain. *Remote Sensing of Environment,* 124**,** 1-14.

Le Hegarat-Mascle, S., C. Ottle & C. Guerin (2005) Land cover change detection at coarse spatial scales based on iterative estimation and previous state information. *Remote Sensing of Environment,* 95**,** 464-479.

Le Hegarat-Mascle, S. & R. Seltz (2004) Automatic change detection by evidential fusion of change indices. *Remote Sensing of Environment,* 91**,** 390-404.

Liu, D. & S. Cai (2011) A Spatial-Temporal Modeling Approach to Reconstructing Land-Cover Change Trajectories from Multi-temporal Satellite Imagery. *Annals of the Association of American Geographers*.

Liu, D. S., K. Song, J. R. G. Townshend & P. Gong (2008) Using local transition probability models in Markov random fields for forest change detection. *Remote Sensing of Environment,* 112**,** 2222-2231.

Liu, H. & Q. Zhou (2004) Accuracy analysis of remote sensing change detection by rule-based rationality evaluation with post-classification comparison. *International Journal of Remote Sensing,* 25**,** 1037-1050.

Liu, X. & R. G. Lathrop (2002) Urban change detection based on an artificial neural network. *International Journal of Remote Sensing,* 23**,** 2513-2518.

Lu, D., P. Mausel, E. Brondizio & E. Moran (2004) Change detection techniques. *International Journal of Remote Sensing,* 25**,** 2365-2407.

Lunetta, R. S., J. F. Knight, J. Ediriwickrema, J. G. Lyon & L. D. Worthy (2006) Land-cover change detection using multi-temporal MODIS NDVI data. *Remote Sensing of Environment,* 105**,** 142-154.

Qiao, Y., H. P. Liu, M. Bai, X. D. Wang & X. L. Zhou (2010) Extracting impervious surfaces from multi-source satellite imagery based on unified conceptual model by decision tree algorithm. *Science China-Technological Sciences,* 53**,** 68-74.

Ridd, M. K. & J. J. Liu (1998) A comparison of four algorithms for change detection in an urban environment. *Remote Sensing of Environment,* 63**,** 95-100.

Salmon, B. P., J. C. Olivier, K. J. Wessels, W. Kleynhans, F. van den Bergh & K. C. Steenkamp (2011) Unsupervised Land Cover Change Detection: Meaningful Sequential Time Series Analysis. *Ieee Journal of Selected Topics in Applied Earth Observations and Remote Sensing,* 4**,** 327-335.

Singh, A. (1989) Digital Change Detection Techniques Using Remotely-Sensed Data. *International Journal of Remote Sensing,* 10**,** 989-1003.

van Oort, P. A. J. (2007) Interpreting the change detection error matrix. *Remote Sensing of Environment,* 108**,** 1-8.

Wang, L., J. Chen, P. Gong, H. Shimazaki & M. Tamura (2009) Land cover change detection with a cross-correlogram spectral matching algorithm. *International Journal of Remote Sensing,* 30**,** 3259-3273.

Wilson, E. H. & S. A. Sader (2002) Detection of forest harvest type using multiple dates of Landsat TM imagery. *Remote Sensing of Environment*, 80**,** 385-396.
Zhang, Q., J. Wang, X. Peng, P. Gong & P. Shi (2002) Urban built-up land change detection with road density and spectral information from multi-temporal Landsat TM data. *International Journal of Remote Sensing*, 23**,** 3057-3078.