TROPICAL FOREST CHANGE DETECTION BY A TREND ANALYSIS OF TIME SERIES SATELLITE IMAGES

Gen Takao[1]
1 Forestry and Forest Products Research Institute, Tsukuba 305-8687, Japan
Email: takaogen@affrc.go.jp
Khali Aziz Hamzah[2], Azahari Mohd Faidi[2], Hamdan Omar[2]
2 Forest Research Institute Malaysia, FRIM Kepong, 52109 Selangor, Malaysia

KEY WORDS: Landsat, Cloud-free images, Multilinear regression, Virtual time series images, Peninsular Malaysia

ABSTRACT: Time series Landsat images can be used retrospectively to map land covers and their changes over decades. In humid tropics, however, clouds and uneven hazes have often reduced chances of observing a wide area simultaneously. The objective of this study is to develop a virtual regular-interval time series of cloudless satellite images in a tropical forest area and map the forest changes through the time. In total, 317 Landsat TM/ETM+ images taken in 1994-2012 were used for the analyses (Path: 126 & 127, Row: 057 & 058), which covered about 90,000 km2 of a part of Peninsular Malaysia. As pre-processings, clouds and their shadows were removed, and a dark-vegetation based atmospheric correction was applied for each image. Then, all the images were overlaid to each other after projected to Rectified Skew Orthomorphic Malaya Grid (RSO). For each pixel, trend of the reflectance for Bands 3, 4 and 5 were analyzed against the acquisition dates by multilinear regression, and abrupt land cover changes were detected by fitting multiple regression lines and selecting the best fitting model by the Bayesian Information Criterion, then finally a virtual annual TM/ETM+ images in 1996-2010 was obtained. Each of the annual images was then classified into Forest, Non-forest, Plantations and Water by the classification tree. The overall accuracy was 72.5%. By visual checking, the annual TM/ETM+ images were smooth both geographically and chronologically, and the resultant classification demonstrates virtually no unrealistic land cover changes, e.g. from Forest to Non-Forest then to Forest in a short period. The annual land cover maps indicate a trend of increasing Non-Forest and Plantations while reducing Forest in the area during the period. By using the virtual time-series images, land cover mapping and change detections can become standardized and simplified.

1. INTRODUCTION

Forest management of a country requires a veracious monitoring of its forest distribution. Developing countries that enroll to REDD-plus (Reducing Emissions from Deforestation and forest Degradation in developing countries, etc.), in particular, are requested to develop robust and transparent national forest monitoring systems (UNFCCC 2009). Remote sensing is an indispensable tool to establish such systems that can monitor the on-going changes as well as the past trend of changes that have been occurred in the forest (Hirata et al. 2013). Time series Landsat images are a suitable data source to map land covers and their changes over decades.

In humid tropics, however, clouds and uneven hazes have often reduced chances of observing a wide area simultaneously, and prevented direct and/or indirect comparisons of images of a location through time. Such problems should be resolved in a simple and automatic manner so as to develop the national-level forest monitoring system based on remote sensing.

Recently, a few studies proposed the trend analyses of time-series Landsat images (Hansen et al. 2013, Zhu and Woodcock 2014). Hansen et al (2013) shows some discrepancies in the trend of forest cover against the existing statistics and studies, which indicates for national level forest monitoring an appropriate combination of image processing technology and understanding of local forest characteristics.

Objectives of the study is to apply a time series analysis of Landsat images and to detect the trend of forest and land cover changes over a part of Peninsular Malaysia for nearly two decades.

2. STUDY AREA AND MATERIALS

Study area is a part of Peninsular Malaysia that is covered by four Landsat coverages, i.e. 126/057, 126/058, 127/057 and 127/058, which covers about 90,000 km^2 of the land area (Figure 1). In 2013, total land area of Peninsular Malaysia is about 131,800 km^2, among which 58,300 km^2 are forested area, or the forest cover is about 44% (Forest Department Peninsular Malaysia 2013).

All the Landsat TM/ETM scenes used in the study were downloaded from USGS Earth Explorer. All the scenes within the above-mentioned coverages from January 1st, 1994, until December 31st, 2012, with the cloud cover of 60% or less are primarily selected. After removing a few scenes by visual checking, due to too much cloud cover, wrong geo-reference, noises, etc., finally 317 scenes are selected for the study.

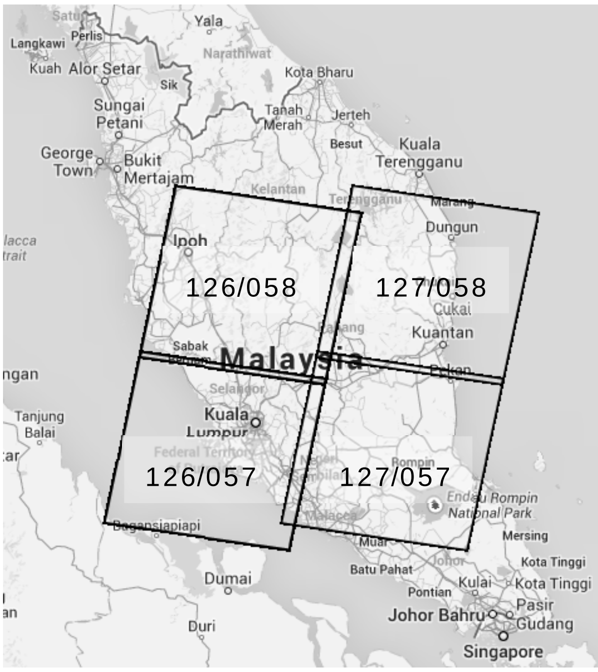


Figure 1 Study area and the four Landsat coverages © Google

3. METHODS

3.1 Scene-based pre-processing

After downloaded, a series of pre-processing were applied to each TM or ETM scene to make reflectance of a pixel comparable to each other through time. Clouds and their shadows were removed by using Fmask (Zhu and Woodcock 2012).

Then, an atmospheric correction was applied based on Liang's method (Liang et al. 1997). It is an empirical correction method with an assumption of the spectral reflectance of dark vegetation. Since dark vegetation, e.g. forests and/or plantations, exists across Peninsular Malaysia, the atmospheric thickness could be estimated locally, and, by interpolating them with a moving window, uneven atmospheric thickness was corrected properly throughout a scene.

Map projection of each scene was transformed from UTM to Rectified Skew Orthomorphic Malaya Grid (RSO).

3.2 Trend estimation from time-series pixels

Among six reflection bands of TM/ETM, Bands 3, 4 and 5 were analyzed hereafter. By overlaying the pre-processed scenes to each other, an irregular interval time series of spectral reflectance was derived at a given pixel (Figure 2).

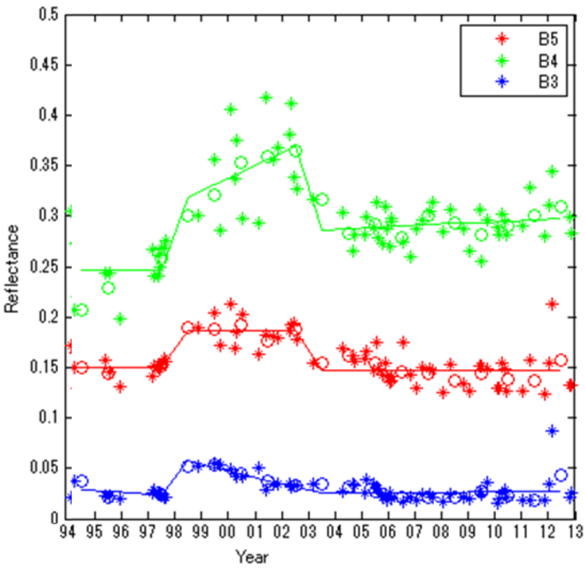
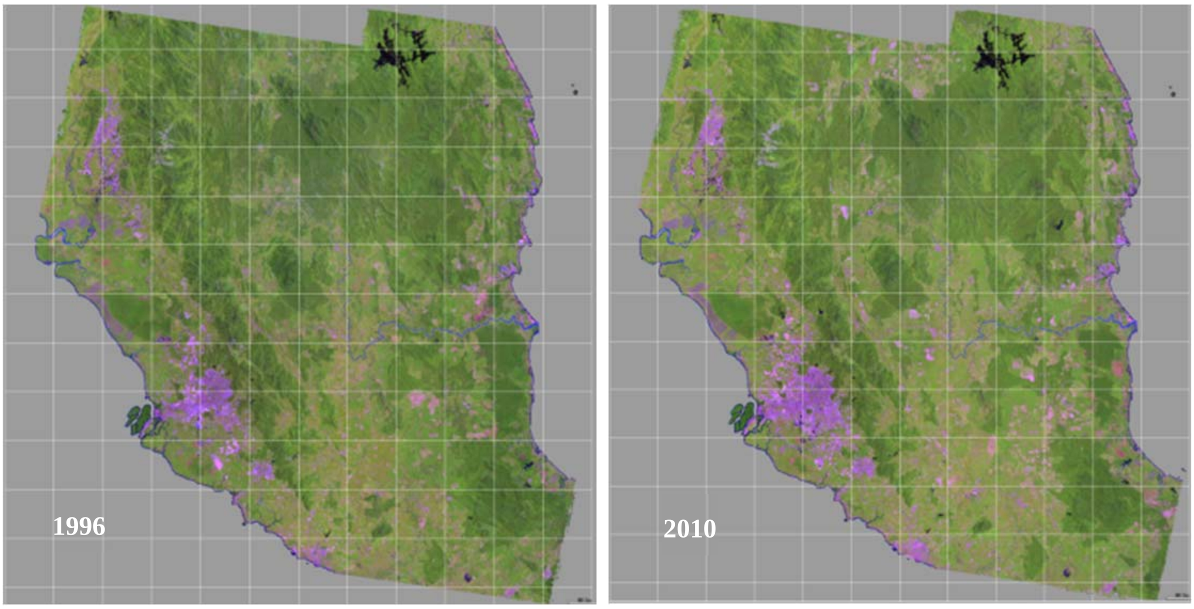


Figure 2 Spectral reflectance of Bands 3, 4 and 5 of Landsat TM/ETM scenes through the study period at an example pixel. Asterisk (*) and circle (o) indicate reflectance of an individual scene and the annual average, respectively. Lines represent the estimated trend and abrupt changes as described in 3.2.

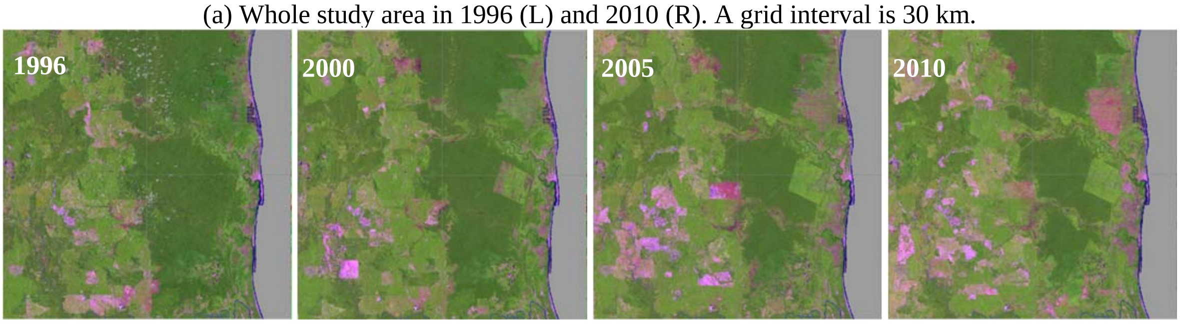
There are two types of change occurred in the reflectance time series; a continuous trend and an abrupt change. The continuous trend is a constant change through a certain time period in accordance with the nature of the land cover. It also includes a stable condition, i.e. no change, as a special case. The abrupt change occurs when characteristics of the land cover is suddenly changed. For example, clear cuts of forests induce abrupt changes of reflectance from the dark vegetation's to the bare soil's.

In this study, we first estimated the continuous trend through whole the study period of the time series, assuming no abrupt change during the period for each pixel. Then, we searched abrupt changes in the time series by the dynamic programming (Bai and Perron 1998). The continuous trend was fitted by a multivariate regression (Equation 1). Then the goodness of fit is compared by the Baysian Information Criterion (BIC).

$$\boldsymbol{b} = \begin{pmatrix} b_5 \\ b_4 \\ b_3 \end{pmatrix} = \boldsymbol{\beta} t + \boldsymbol{\alpha} + N(\mathbf{0}, \Sigma) \qquad (1)$$



(a) Whole study area in 1996 (L) and 2010 (R). A grid interval is 30 km.



(b) An example area of 60 km by 60 km from 1996 to 2010.

Figure 3. The annual mosaicked images. RGB = Bands 5, 4 & 3.

When estimated the abrupt changes, we introduced three assumptions; the first was that a land cover should last three years or longer, the second was that there should be no more than three times of abrupt changes occurring at a pixel during the 19 years of the study period, and the third was that an abrupt change should occur only on the New Year Day of a year.

For each pixel, the continuous trend and abrupt changes was estimated as broken lines through time (Figure 2), from which the spectral reflectance was estimated for July 1st of every year from 1996 to 2010 to construct the annual mosaicked images of the study area.

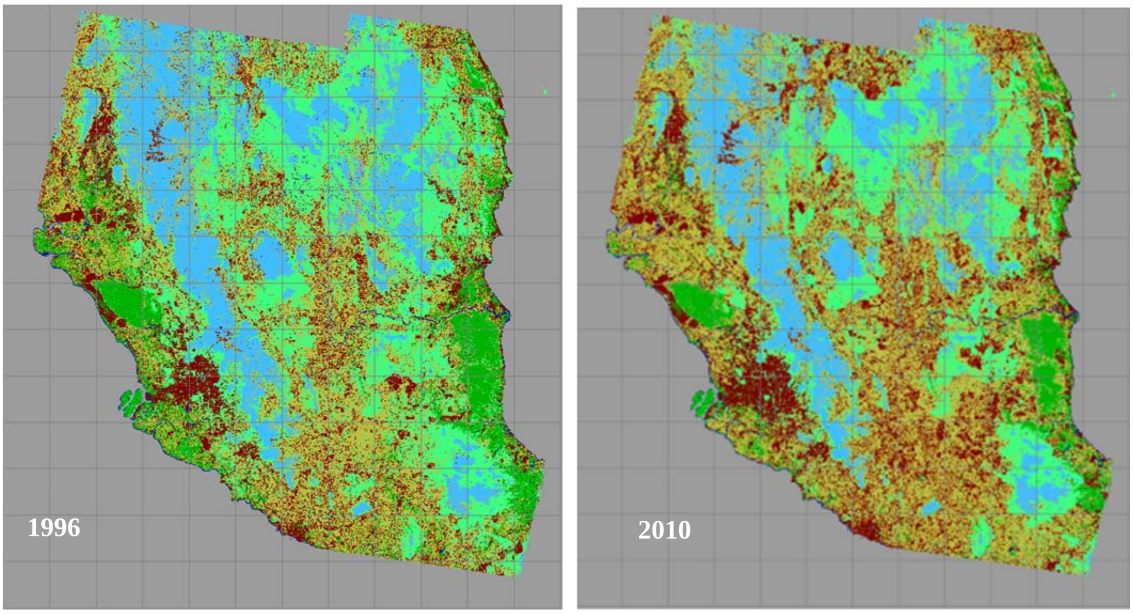
3.3 Land cover classification of the annual mosaicked images

Each of the annual mosaicked images was classified into “Forest,” “Non-forest,” “Plantations” and “Water” using the classification tree. “Forest” was further divided into “Hill Forest,” “Lowland Forest,” and “Wetland Forest” according to the elevation and terrain. About 1,100 points of the ground truths were collected by interpreting Google Earth and divided into the supervised data and the evaluation data.

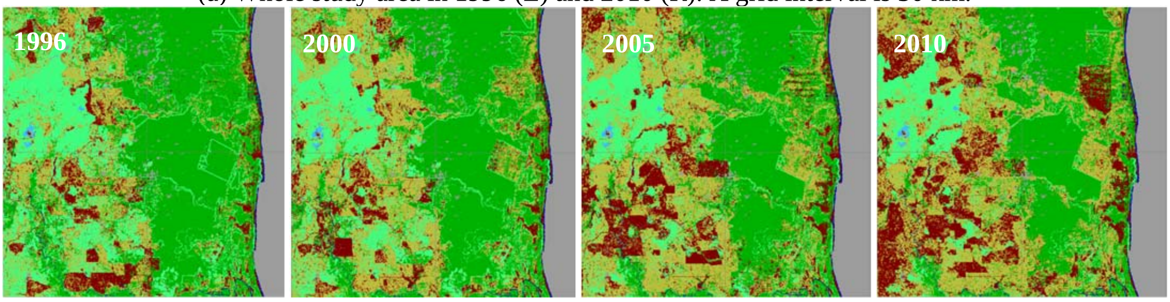
4. RESULTS AND DISCUSSION

4.1 Annual mosaicked images

Figure 3 (a) shows the annual mosaicked images of the whole study area in 1996 and 2012, and Figure 3 (b) shows an example part of the study area in 1996, 2000, 2005 and 2012. Visual evaluation indicates that the annual mosaicked images are seamless and cloudless as if the study area was captured at a moment of perfectly cloud-free day.



(a) Whole study area in 1996 (L) and 2010 (R). A grid interval is 30 km.



(b) An example area of 60 km by 60 km from 1996 to 2010.

Figure 4. Land cover classification of the annual mosaicked images. Same areas and years as Figure 3 are presented. Legend Hill Forest, Lowland Forest, Wetland Forest Plantation, Non-Forest, Water

From visual evaluation of systematically located sample points over the study area, abrupt changes seemed adequately detected (Figure 2). The assumption that a land cover should last three years or longer seems reasonable; without this assumption or with a shorter limit period assumption, sometimes unrealistically steep trend clipped by false abrupt changes was estimated. We suppose it was caused by the variation of reflectance and the relatively low frequency of cloud-free pixel acquisition in a short period. A longer limit period assumption would result in a lower resolution of changes.

Another assumption that no more than three times of abrupt changes at a pixel during the study period was introduced to reduce the calculation load and eventually it can be removed as both the hardware and the software improve. However, during the 19 years period and especially in the forested area, more frequent land cover changes than three times were not visually found. When it is removed, we suppose that it would be more sensible to the change of trend (coefficients), e.g. saturation of reflectance after the plantation canopy closes. Further evaluation is required.

Fmask (Zhu and Woodcock 2012) cannot completely remove clouds and shadows. Sometimes reflectance of cloud or shadow is contaminated in the time series of land cover reflectance, resulted in unstable and unrealistic trend estimation. For more stable trends, robust regression methods should be considered.

Terrain correction is not applied to the reflectance in this study. Furthermore, annual cycle of reflectance change is not considered. Without these considerations, still the abrupt change detection was successful, however, they might improve the trend estimation and the classification.

4.2 Trend of forest area

The classification results in the exemplified part and years corresponding to Figure 3 (b) are presented in Figure 4.

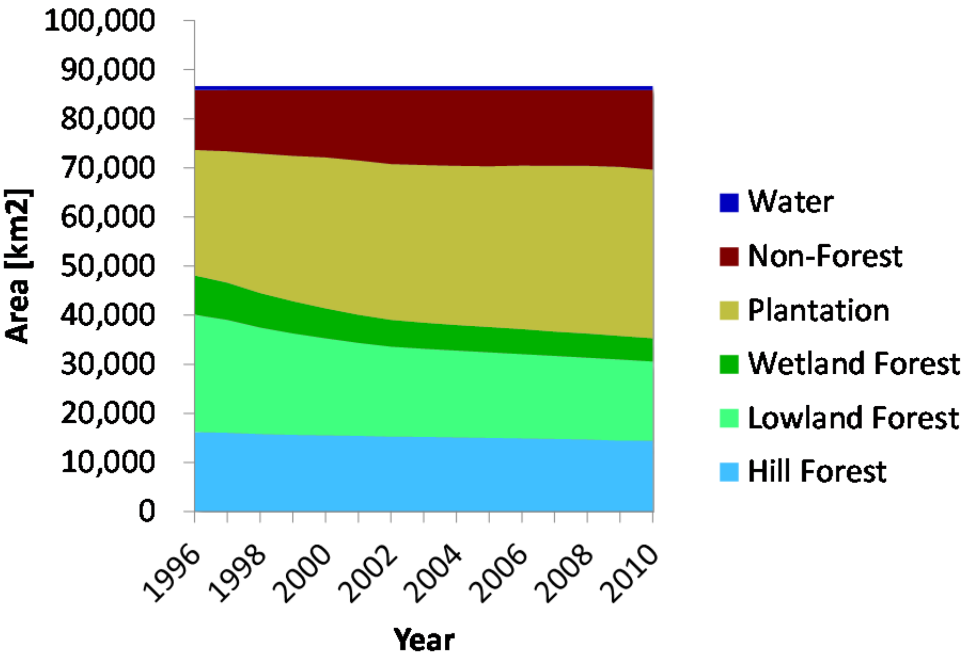


Figure 5 Trend of land cover changes in the study area from 1996 to 2010

The overall accuracy of the classification was 72.5%, while $\hat{\kappa}$ was 0.60. It should be noted that the annual mosaicked images are not independent to each other, because they are products from the trend analysis over the study period. Thus the accuracy values represent the quality of the time series land cover maps as a whole.

The annual trend of land cover and forest area during the period 1996 – 2010 is presented in Figure 5. It is apparent that forest is gradually decreasing in the earlier part of the study period then almost stabilized in the latter part, while plantation is increasing throughout the period. This trend is coincident with the study in a longer period over Peninsular Malaysia (Miyamoto et al. 2014). The whole Peninsular Malaysia should be analyzed by the current study's method for the full scale comparison.

5. CONCLUSION

In this study, we demonstrated to construct a time series of annual mosaicked images from accumulated Landsat TM/ETM scenes and analyze the trend of forest and land cover changes. By combining the cloudless part of different scenes, variation of reflectance is canceled and the abrupt changes and continuous trend of reflectance from land covers are successfully estimated. The annual mosaicked images would make land cover mapping and change detections standardized and simplified, and further application of the cloudless image would be proposed.

This study is to be expanded to whole Peninsular Malaysia. In addition, further studies need to be conducted on terrain corrections, progressive expansion of the trend estimation, classification improvement, among others.

We are grateful to the Forest Department Peninsular Malaysia for their kind support for the research in the permanent forest reserves. This research is funded by a granted project of Forestry Agency, Japan, "Development of REDD Promotion Framework."

Reference

Bai JS, Perron P. 1998. Estimating and testing linear models with multiple structural changes. Econometrica 66: 47-78.

Forest Department Peninsular Malaysia. 2013. FORESTRY STATISTICS FOR THE YEAR 2013.

Hansen MC, et al. 2013. High-Resolution Global Maps of 21st-Century Forest Cover Change. Science 342: 850-853.

Hirata Y, Takao G, Sato T, Toriyama J, eds. 2013. REDD-plus Cookbook - How to measure and monitor forest carbon - Tsukuba: REDD Research and Development Center, Forestry and Forest Products Research Institute.

Liang SL, FallahAdl H, Kalluri S, JaJa J, Kaufman YJ, Townshend JRG. 1997. An operational atmospheric correction

algorithm for Landsat Thematic Mapper imagery over the land. Journal of Geophysical Research-Atmospheres 102: 17173-17186.
Miyamoto M, Parid MM, Aini ZN, Michinaka T. 2014. Proximate and underlying causes of forest cover change in Peninsular Malaysia. Forest Policy and Economics 44: 18-25.
UNFCCC. 2009. Methodological guidance for activities relating to reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries. Decision 4/CP.15.
Zhu Z, Woodcock CE. 2012. Object-based cloud and cloud shadow detection in Landsat imagery. Remote Sensing of Environment 118: 83-94.
Zhu Z, Woodcock CE. 2014. Continuous change detection and classification of land cover using all available Landsat data. Remote Sensing of Environment 144: 152-171.