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Development of near-real time forest monitoring (Phase I: Data preparation)

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Abstract

Deforestation and forest degradation are still major problems in Indonesia, even though the magnitude has been decreasing recently. In order to overcome these problems, an immediate action with accurate and up-to-date information is essensial. Expired information, due to out of date is usually hamper the immediate response. Remote sensing technology seems to be a powerful tool to monitor the change of forest cover. However, an availability of cloud free satellite images in tropical region is another of obstacle. Regarding to the deforestation and forest degradation issues, it needs to develop near-real time forest monitoring, that publicly available to support the transparency in managing the natural resources. As an initial work of the development of early deforestation detection system, we employed the long-term MODIS image datasets, acquired from 2001 to 2013 with 286 time series data totally. Although MODIS data have some advantages in providing basic information related to the real time change detection, these time-series data inevitably contain disturbance caused by atmospheric variability and aerosol scattering. This study is an early phase in developing the near-real time forest monitoring system, which is focused on providing a reliable image datasets to support this system. The results suggested that MODIS data offer great opportunities to support the near-real time forest monitoring system at large scale.

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Keywords: Near-real time monitoring; forest cover; MODIS; Indonesia

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1. Introduction

Monitoring, Reporting and Verification (MRV) as well as Moratorium work stream of the Reducing Emissions from Deforestation and Forest Degradation Plus, Agency of Republic of Indonesia (BP-REDD+) is mandated to handle the process of national and nested sub-national REDD+ measurement and reporting (MR) system in accordance with IPCC Good Practice Guidance. The REDD+ MRV and Moratorium will establish a multi-tiered measurement system. Viewed this way, it is urgently need to develop a near-real time deforestation detection system that provides important information in Monitoring, Reporting and Verification (MRV) that should be the main responsibility of BP-REDD+ agency (President Decree No. 62/2013). In this context, accurate and up-to-date information is required immediately.

Remote sensing technology seems to be a powerful tool to monitor the forest cover changes continuously in terms of space and time. To support the MRV system, application of high-temporal satellite imagery in a large scale will provide accurate, sufficient, and significant information regarding to the deforestation events [1], and it is possible to develop the near-real time deforestation detection system especially for Indonesia's forest land.

Regarding to the forest cover change, the monitoring of vegetation dynamics continuously of land surface is increasingly essensial and it is a way to detect a rapidly forest cover changes. Vegetation dynamics monitoring system have attracted attention as it provides a better understanding of land changes, including the forestlands [2]. Characterization of vegetation dynamics of forestlands has often been made using vegetation index values [e.g.: 3,1]. The temporal dynamics of those index values are useful in detecting the forest cover changes and their distributions [4].

Although MODIS data have some advantages in providing basic information related to vegetation dynamics, time-series of these data inevitably contain disturbances caused by atmospheric variability [5] and aerosol scattering [6]. Such noise degrades the data quality and introduces considerable uncertainty in temporal sequences, complicating the analysis by introducing significant variations in time series data. Therefore, noise reduction or fitting a model to data observation is needed before use it to detect the vegetation cover change in the forestlands.

Various strategies for image preprocessing have been applied such as: polynomial and median filters [7], a moving window to select the local maximum VI [8], Temporal Window Operation/TWO [9], logistic curve fitting [10], the asymmetric Gaussian function fitting approach [11], Principal Component Analysis /PCA [12], and the Savitzky-Golay filter approach [13]. Several spectral-frequency techniques have also been used, including Fourier-based fitting methods for separating the high-frequency components of noise and the low-frequency components of seasonal changes of VI [1]. In addition, wavelet decomposition that has been used recently to characterize crop penology [14], to determine changes in the expansion and intensification of crops [2] as well as to investigate vegetation dynamics in terrestrial ecosystem [15]. In this study, two filtering approaches are applied to MODIS time-series datasets based on a median moving window and linear interpolation to smooth and reduce the discontinuous/sharp spike data of the datasets.

The main objective of this study is to provide a reliable datasets in order to support the developing of early warning system for deforestation by using remote sensing technology for Indonesia's forestland with high accuracy results in accordance with the MRV program of BP-REDD+.

2. Methodology

2.1. Satellite Images

2.2.1. MODIS

MODIS has a viewing swath width of 2,330 km and covers the entire surface of the earth every one or two days. The data is acquired at 36 spectral bands in three spatial resolutions of 250m, 500m, and 1,000m. As a result, a lot of information related to the features of the land, oceans and atmosphere have been derived from MODIS data and have been used for studies of the processes and trends either for local or global scales [16].

MODIS surface reflectance includes band 1 to 7 that has 0.648 μm, 0.858 μm, 0.470 μm, 0.555 μm, 1.240 μm, 1.640 μm, and 2.13 μm of specral reflectance. These datasets are the input for all of the MODIS land products, such as surface albedo/BRDF, land cover, vegetation indices, leaf area index (LAI) and biophysical variables. The quality of these reflectance products depend directly on the quality of atmospheric conditions. Therefore, the atmospheric correction algorithm needs to be applied to the data in order to correct the effects of gaseous, aerosol scattering as well as adjacency effects caused by variation of land cover, Bidirectional Reflectance Distribution Function (BRDF), atmosphere coupling effects, and contamination by thin clouds.

2.2.2. LANDSAT

Landsat imagery is used to examine the details of forest cover changes. The spatial resolution of 30 m is adequate to determine the changes and it is large enough to cover the change on MODIS image pixels. Landsat 5 TM, Landsat 7 ETM and Landsat 8 are available for those purposes.

2.2. Deforestation Indices

The daily MODIS-surface reflectance product is provided by the U.S. Geological Survey, Land Processes Distributed Active Archive Center (USGS LPDAAC). The dataset is distributed in GeoTIFF (Georeferenced Tagged Image File Format) and its coordinate system is geographic coordinate systems (GCS) on datum World Geodetic System of 1984 (WGS-1984). In this dataset, to select the best surface reflectance value, MODIS band quality ratings is applied to retain only pixels rated as "acceptable" that would be used in the analysis.

The MODIS surface reflectance has 3 spectral bands which are red (band 1), near infrared/NIR (band 2) and shortwave infrared (band 6) spectral wavelengths. These bands provide the characterization of the main vegetation properties. For instance, the red reflectance (615–700 nm) is reduced by the chlorophyll absorption and the near infrared reflectance (772–892 nm) reaches a maximum for fully developed healthy canopies due to high light scattering. From these two spectral ranges, the activity of vegetation is evidenced.

(1) Normalize Difference Vegetation Index (NDVI) is commonly used to measure the reliability of spatial and temporal inter-comparison of terrestrial photosynthetic activities. In other words, it is a measure of vegetation greenness. The NDVI is defined by the equation:

$$NDVI = \frac{\rho^*_{NIR} - \rho^*_{RED}}{\rho^*_{NIR} + \rho^*_{RED}} \tag{1}$$

Where ρ^*_{NIR} and ρ^*_{RED} are the remote sensing reflectance of the vegetation in near infrared and red portion of the spectrum, respectively.

(2) Open Area Index (OAI). The capability of OAI to detect open area is based on the comparison between shortwave infrared/SWIR (1600 nm) and NIR (800 nm) spectral band, which are sensitive to bareland as well as liquid water thickness. For this reason, the NIR/SWIR indices, such OAI, is proposed to detect forest cover change. The OAI is defined by the equation:

$$OAI = \frac{\rho^*_{SWIR} - \rho^*_{NIR}}{\rho^*_{SWIR} + \rho^*_{NIR}} \tag{2}$$

Where ρ^*_{SWIR} and ρ^*_{NIR} are the remote sensing reflectance of the vegetation in shortwave infrared and near infrared portion of the spectrum, respectively.

2.3. Image Pre-processing

At regional scale, MODIS time series images are essential to recognize the forest cover change in much finer temporal resolution; consequently it should be possible to provide broad scale data to detect the occurrence of deforestation rapidly as an early warning forest detection system (near-real time detection). However, these time-series datasets are inevitably contain disturbances caused by cloud presence, atmospheric variability, and aerosol scattering. Therefore, to get a greater percentage of clear-sky data in the monthly composite MODIS data (MODIS composited 30-days), two filtering approaches were applied by:

(1) A median moving window over 3 time series data in order to smooth and reduce the discontinuous/sharp spike data of MODIS time series (Fig 1),

(2) A linear interpolation to estimate unknown values caused by cloud. Linear interpolation is the simplest method of getting values at positions in between the data points (Fig 2).

Once these filtering applied on the temporal vegetation pattern, the vegetation pattern can be defined more clearly. These images are then clipped to cover only Indonesia area and sequentially stacked to produce the NDVI and OAI time-series datasets. Accordingly, the surface can be characterized by regular NDVI and OAI sequence at 12 time series per year.

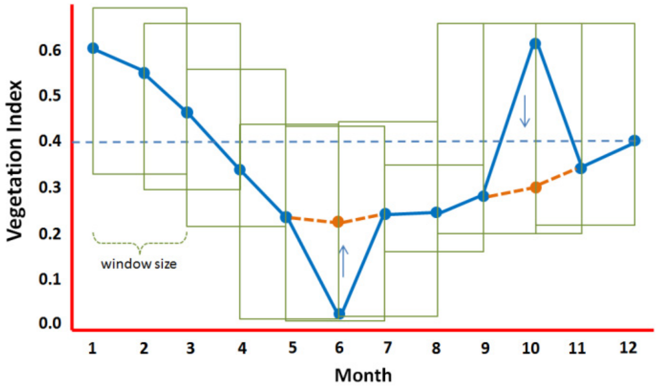

Fig 1. Illustration of average moving window over 3 time series datasets following the average/median of datasets

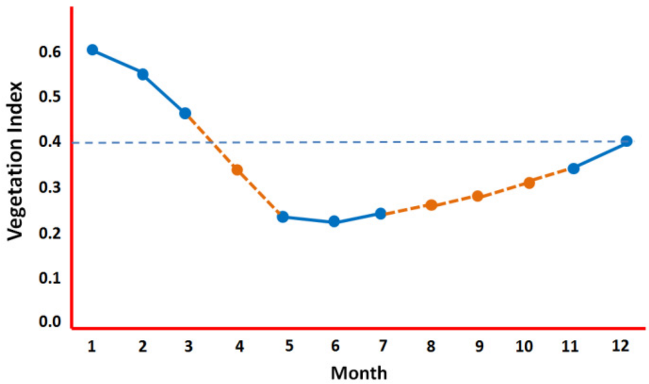

Fig 2. A linear interpolation to estimate unknown values caused by cloud

As the main datasets, MODIS image processing is designed to achieve the analysis of continual vegetation patterns, and to detect their changes on forest cover areas, which is classified as deforestation.

3. Results and Discussion

3.1. Image Filtering

The result of filtering pattern of a pixel from an image is given in Fig 3. Comparison between the filtered image and original image is shown in Fig 4. The figures show that the filtering approach filters some noises (de-noise) of MODIS time-series data; so that the vegetation pattern specifically can be determined.

In terms of a reference datasets of forest cover change [17], those changed area can be identified by characterizing the dynamics change of land cover. For example as mentioned in Fig 5., information that could be obtained from the vegetation dynamics analysis and forest cover change by the natural phenomena such as forest fire.

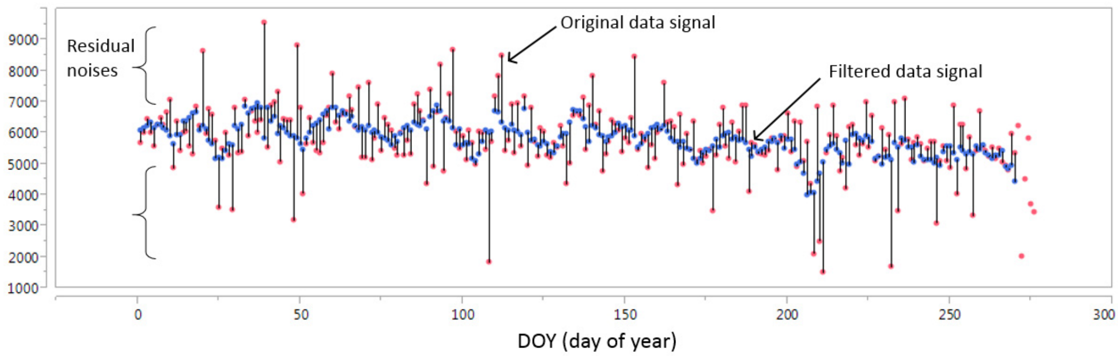

Figure 3. Vegetation dynamics pattern of an original EVI data and de-noising result (filtered signal)

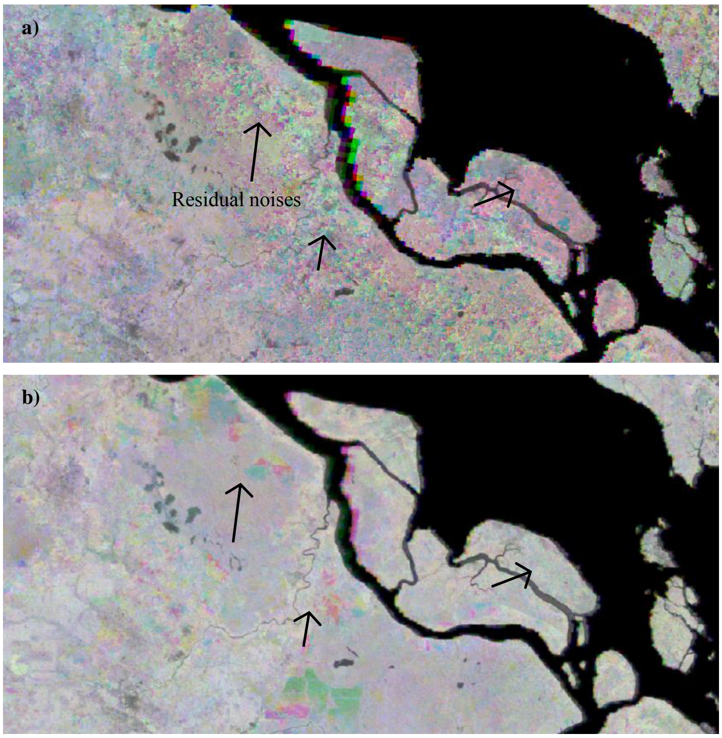

Figure 4. a) Image before and b) after transformation.

Based on the trial application of vegetation pattern change analysis, this approach is able to detect not only several trajectories/patterns of vegetation or non-vegetation transformation, but also able to identify and monitore the re-vegetation process of non-vegetation area. Even if those changed areas smaller than the area extent indicated in the field due to the inability of MODIS data to resolve an area less than 6.25 ha (250 m x 250 m).

The temporal pattern analysis of MODIS vegetation indices has significant advantages for both in capturing the actual time of the forest cover change events and in monitoring the vegetation growth process. However, such capabilities are limited by the spatial resolution of the data. The use of multi-temporal data sets and change thresholds will be necessary to develop methodologies that utilize information on inter-annual variations in order to increase the accuracy of the near-real time system of detecting the deforestation.

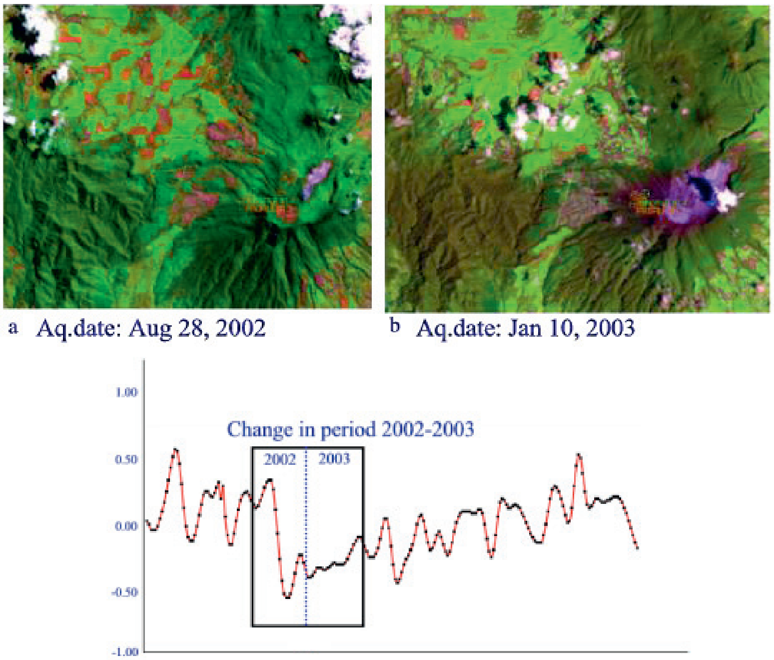

Fig 5. Images indicate an event of a vegetation cover change by forest fire occurred on 2002.

4. Conclusions

This study is an early phase in developing the near-real time forest monitoring system, which is focused on providing a reliable image datasets to support the system. The two filtering approaches by a median moving window and interpolation were applied into MODIS datasets to filter out some noises. The filtered MODIS could be used to determine the change event of the lands, including the deforestation.

The methodology proposed in this study provides sufficient and useful information in monitoring the vegetation changes; this includes the location, time and trajectories of the changes. Consequently, it should be possible to provide data on the deforestation and forest degradation in broad scale especially for Indonesia context.

However, the mixed pixel issue is quite problematic in using MODIS datasets, the results show that the characterizing vegetation dynamics is an alternative approach to develop the near-real time forest monitoring system.

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