

ESTIMATION OF PERCENT TREE COVER IN EURASIA USING MODIS DATA IN 2003 AND THE COMPARISON OF ESTIMATION BETWEEN 2003 AND 2008 IN SOME PARTS

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ABSTRACT:

Global percent tree cover is an important parameter to understand global environment. Some attempts to produce global percent tree cover maps have been made so far. But the accuracy of these maps is not so high. In this study, percent tree cover of some areas in Eurasia was estimated using a supervised regression tree algorithm from MODIS data in 2003 as a preliminary research. Simulated training data were created from a lot of ground truth data consisted of various land cover types to improve the accuracy of the estimate. The ground truth data were collected from QuickBird images and Google Earth images. In South Asia and a part of Indonesia, the percent tree cover in 2008 was also estimated and compared with the result in 2003 to investigate the stability of the estimation result and the possibility of change detection. In areas where training data were collected, the accuracy of the estimate improved. This means the necessity of constructing regression tree models area by area to increase the accuracy.

1. INTRODUCTION

Forests provide foundations for life on earth. They serve as habitats for it and regulate the climate and water resources. But they have recently been converted or degraded to unsustainable forms of land use because of urbanization and deforestation by expanding human populations, and that sometimes leads to increasing flood and soil erosion. About 16.1 million hectares of natural forests were lost annually in the world during the 1990s (FAO, 2000; FAO, 2001). Trees are important structural members of forests. They remove carbon dioxide from the atmosphere when they grow, and emit it when they decay or burn.

Some attempts to produce global percent tree cover maps have been made so far (DeFries, 2000a; DeFries, 2000b; Hansen, 2003; Rokhmatuloh, 2007; Geospatial Information Authority of Japan, 2008). Continuous field maps have the advantage to change detection in spatially complex land covers compared with traditional discrete classifications (Hansen, 2002). These maps can be used for deriving carbon cycle models as one of the environmental parameters in it, deciding environmental policies and understanding the present environmental situation on school education. However, these maps of global tree cover percentage produced by some organizations or researchers were not so accurate. The final goal of our study is to produce a precise global percent tree cover map in a specific year and to investigate the change of tree cover.

In this study, percent tree cover was estimated for some areas in Eurasia as a preliminary research. It was estimated by supervised regression tree algorithm using the data from the Moderate Resolution Imaging Spectroradiometer (MODIS)

instrument. The original MODIS dataset, Global MODIS 2003 data processed by CEReS Chiba University (Al-Bilbisi, 2007), was converted into ten annual predictor variables, such as yearly maximum NDVI value. The produced predictor variables were used for constructing regression tree models and estimating the percent tree cover. There are some methods for estimating percent tree cover, for example spectral mixture model, artificial neural network and multiple linear regression. Regression tree algorithm was one of the most accurate methods among them (Berberoglu, 2009), although each method has advantages and drawbacks. QuickBird images and Google Earth images were used for getting ground truth data. Because actual land covers are very complicated, various land cover types of training data are needed to make more precise estimate. For instance, cropland, urban area and many kinds of trees and soils are there in one pixel (1km x 1km). To deal with this problem, simulated training data were created by combining a lot of ground truth data.

In South Asia and a part of Indonesia, the percent tree cover in 2008 was also estimated and compared with the result in 2003. To estimate the tree cover percentage, South Asia was divided into four parts, and the estimate was made using only ground truth data inside each area.

The definition of "tree" and "percent tree cover (or tree crown cover)" are a little bit different according to research papers (Hansen, 2003; FAO, 2004; Heiskanen, 2008). In botany, tree is defined from following aspects: (a) whether it is perennial or not, (b) whether it has a self-supporting stem or not, (c) whether the thickness of secondary tissues is increasing or not, (d) whether it repeatedly flowers and fruits or not, (e) whether the girth of its stem increases or not, (f) what is its height, etc.

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(Thomas, 2000). But it is difficult to distinguish trees from other vegetation by satellite remote sensing technique. In this study, the percent tree cover meant the percentage of the ground surface area covered by a vertical projection of the foliage and branches of trees at the time when trees have grown thick. Small openings inside each crown and small gaps between crowns are included. The definition of “tree” is a woody perennial with a single self-supporting main stem, and its minimum height is approximately 3-6m. Trees for agricultural production or in gardens, and trees on plantations are included. Bamboos are also included in trees. This definition is only the concept because it is difficult to know these characteristics from satellite images, as we mentioned above.

2. STUDY AREA

Percent tree cover was estimated for 9 areas in Eurasia. 7 areas were in Asia, which ranged from West Siberia to Indonesia, and 2 areas were in Europe, which were part of Iberia peninsula and part of Scandinavia peninsula (Figure 1). These areas cover various land cover types from tropical zone to arctic zone. Training data were obtained from only 7 Asian areas to examine whether these training data were enough to estimate the tree cover percentage at global scales.

In South Asia (5°30' to 35°00'N and 72°00' to 97°00'E) and a part of Indonesia, the percent tree cover in 2008 and 2003 was also estimated for assessing the stability of the estimation result and the possibility of change detection (Figure 1). There are a lot of deforested areas during these five years in Indonesia, and not so much changed areas in India.

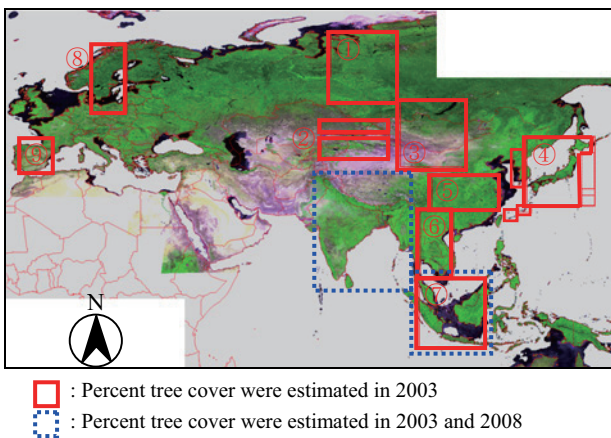


Figure 1. Location map of the study area

3. DATA USED

3.1 Estimation of percent tree cover

Global MODIS 2003 data processed by CEReS Chiba University were used for estimation of percent tree cover in 2003. The summary of this dataset is given in Table 1. This dataset was made from MODIS/TERRA Nadir BRDF-Adjusted Reflectance 16-day L3 Global 1km SIN grid product (MOD43B4 NBAR) (Strahler, 1999; Schaaf, 2004). This product is corrected surface reflectance to a nadir view geometry at the mean solar zenith angle during the observation period using a bi-directional reflectance distribution function (BRDF) model. It is a product of 16-day composites. It was mosaicked and re-projected to geographic map projection at

CEReS, Chiba University. Furthermore cloud-contaminated pixels were linearly interpolated using data in 2002 and 2004 to make it cloud-free.

For the estimate of percent tree cover in 2008, MCD43A4 (Nadir BRDF-Adjusted Reflectance 16-Day L3 Global 500m) in 2008 was used (Table 1). These data are distributed by the Land Processes Distributed Active Archive Center (LP DAAC), located at the U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center. This product is 500-m surface reflectance data corrected to common nadir view geometry at the local solar noon zenith angle of the start of the observation period using a BRDF model. Terra and Aqua data are used in the generation of this product (Schaaf). This product was also mosaicked and re-projected to geographic map projection, and cloud-contaminated pixels were linearly interpolated.

Dataset	Spatial resolution	Temporal resolution	Spectral bands
A	32.37 seconds	16 days	Band1-Band7
B	15.00 seconds	16 days	Band1-Band7

Table 1. Summary of global MODIS 2003 data processed by CEReS Chiba University (A) and MCD43A4 product (B)

3.2 Creation of training and validation data

3.2.1 Google Earth imagery: Google Earth images were used for producing training data set and validating result. Training data were collected from only the areas where percent tree cover was almost 100% or 0% because it was difficult to estimate the actual percentage of tree cover from Google Earth images. They were obtained to include various land cover types from tropical zone to arctic zone. Training data of percent tree cover between 0% and 100% were produced by simulation using linear equation.

The advantage of using Google Earth is that high-resolution images of inaccessible places can be obtained with low cost. But Google Earth has some problems for use. One of the problems is the date of acquisition of Google Earth images. Some images in Google Earth were acquired in winter. The tree cover percentage in glowing season could not be estimated in this case. In addition, the year of image acquisition was not always 2003 or 2008. To partially deal with this problem, all collected training data were checked by comparing with the temporal profile of NDVI calculated from MODIS data in 2003 and 2008.

3.2.2 QuickBird imagery: Six pan-sharpened QuickBird images were also acquired for use in validating the result. Percent tree cover of those images was estimated by unsupervised clustering. In case the estimation result was not good, on-screen digitizing method, which was manual extraction of trees according to visual interpretation, was performed. It was sometimes difficult to distinguish between trees and shrubs from QuickBird images like Google Earth images.

3.2.3 Landsat Enhanced Thematic Mapper Plus data:

The acquisition date of Google Earth imagery is not always 2003 or 2008. This means that the tree cover percentage in 2003 or 2008 may be different from that in acquired date of Google Earth images. Landsat 7 Enhanced Thematic Mapper Plus (ETM+) Scan Line Corrector Off (SLC-Off) data, which is

available from the U.S. Geological Survey, was used to deal with this problem. The all images derived from Google Earth were examined by comparing with this Landsat imagery. When there is some possibility of a change of tree cover percentage in the image, the data was not used for ground truth or validation data.

4. METHODS

4.1 Collection of ground truth data

Ground truth data for creating training data were collected from 7 Asian areas. 204 sites in total were selected from various land cover types from tropical zone to arctic zone (Table 2). Only areas where percent tree cover were almost 100% or 0% were used for ground truth data. The tree cover percentage of Google Earth images was estimated by visual interpretation.

Area	Number of collected ground truth sites		
	Forests	Grasslands or agricultural areas	Urban or bare areas
1	19	40	7
2	1	10	3
3	3	5	10
4	25	18	8
5	4	11	2
6	6	12	1
7	6	11	2

Table 2. Site locations and the number of collected training sites, and their dominant land cover types. The “Area” number corresponds to the number of Figure 1.

4.2 Creation of simulated MODIS band values for training data

Training data ranging from 0% to 100% in tree cover percentage were created from equation:

$$S_i = \sum_{j=1}^n a_j V_{ij} \tag{1}$$

where S_i = simulated value of MODIS band i
 V_{ij} = original value of MODIS band i at ground truth site j
 a_j = area ratio of ground truth site j
 j = 1(:forests), 2(:grasslands or agricultural areas), 3(:urban of bare areas)

S_i was calculated at the interval of 5% of a_j . 204 ground truth data collected from Google Earth images were grouped into 53 types, according to its area, land cover type and predictor variables. S_i was calculated for the combinations of these groups. In this study, impossible combinations, for example the combination of forest in Siberia and grassland in Indonesia, were not considered.

4.3 Creation of predictor variables

The selection of predictor variables is important to estimate percent tree cover using regression tree method. In previous researches, a lot of annual variables were used such as maximum value of NDVI (normalized difference vegetation index), average band 1-7 reflectance at three or seven highest NDVI periods, minimum band 1 reflectance, maximum band 2 reflectance, average reflectance in four darkest reflectance periods and amplitude for minimum and maximum reflectance (Hansen, 2002; Hansen, 2003; Rokhmatuloh, 2007). The best variables were selected among them.

In this study, MODIS band values in whole study area and simulated MODIS band values for training data were converted into only 10 annual predictor variables, that is, averaged NDVI value at three highest NDVI periods from period 9 to 18, averaged band 1-7 values at those periods and minimum NDSI (normalized difference soil index) value and averaged SI (shadow index) value at those periods. NDVI, NDSI and SI (Rikimaru, 2002) were calculated from equations:

$$NDVI = \frac{b_2 - b_1}{b_2 + b_1} \tag{2}$$

$$NDSI = \frac{b_6 - b_2}{b_6 + b_2} \tag{3}$$

$$SI = \sqrt[3]{(1 - b_1) \times (1 - b_3) \times (1 - b_4)} \tag{4}$$

where b_i = reflectance of MODIS band i

4.4 Creation of decision tree model

Regression tree models were produced from predictor variables made from simulated training data using Cubist, which is a commercial software for constructing regression tree model by RuleQuest Research Pty. The models were constructed to minimize the number of rules unless the mean absolute error on training data was larger than 5%, in order to avoid over fitting the data and keep the stability of constructed models. Averaged band 3, band 4 and SI of predictor variables were used only in case the mean absolute error of constructed model was larger than 5%, because these bands had some noises in the images.

4.5 Estimation of percent tree cover

Percent tree cover was estimated pixel by pixel from created regression tree models. Regression tree models to apply to each pixel were selected based on the value of its predictor variables, and unbiased estimator of mean value and standard deviation of grouped training data. The averaged percentage of models was adopted as each pixel’s estimated percent tree cover.

4.6 Refinement of percent tree cover estimation

There were some cases where trees could not be clearly distinguished from grass or agricultural areas. For this reason, new decision tree models were created using each band’s reflectance data and NDVI of 23 periods as predictor variables. In these models, only pixels fitted to seasonal change of training data were chosen for tree cover estimate. The accuracy of these new models was higher, but pixels to fit were fewer.

5. RESULTS

The percent tree cover map of the study area was produced from MODIS data in 2003. In this mapping, 63 regression tree models constructed from 10 annual predictor variables according to training data and 55 regression tree models constructed from individual bands of 23 periods were aggregated. The result is shown in Figure 2.

In South Asia and a part of Indonesia, the percent tree cover in 2008 was also estimated using 93 ground truth data in South Asia (Figure 3). In this estimation, South Asia was divided into four parts, and the estimate was made using only ground truth data inside each part. All constructed regression tree models were applied to all pixels inside each part, because only several models (less than 6 models) could be produced in each small area. The percent tree cover in 2003 was estimated from the same regression tree modes as in 2008 using normalized (or converted) attributes to fit the attributes in 2008 by least squares method.

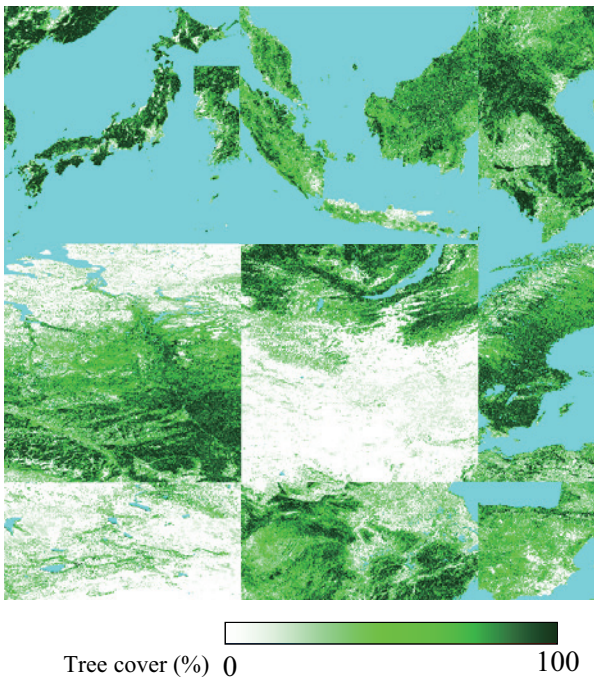


Figure 2. Percent tree cover estimation for study area in 2003

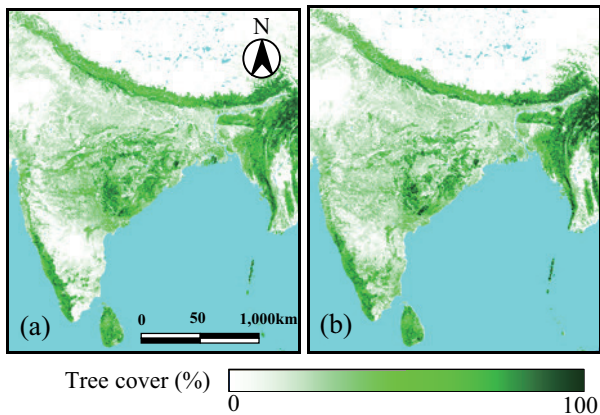


Figure 3. Percent tree cover map for South Asia produced from the data in 2003: (a), and the data in 2008: (b)

6. DISCUSSIONS

The result of the study area was assessed at 71 Asian pixels and 24 European pixels. These assessed pixels were selected from areas where tree cover percentage was widely uniform. The root mean square error of estimated tree cover percentage was 13% at 71 Asian sites (mean absolute error = 10%), and that was 23% at 24 European sites (mean absolute error = 19%). The scatter plot of these pixels showing the relation between estimated and actual (or observed) percentage were displayed in Figure 4. At these 71 Asian sites, the estimate of Global Map-Percent Tree Cover by Geospatial Information Authority of Japan, Chiba University and collaborating organizations was also examined to compare its result with this study (Figure 4). The root mean square error of Global Map-Percent Tree Cover was 26% (mean absolute error = 20%).

The accuracy of the estimation improved by the use of simulated training data with a mean absolute error of 10%. But the majority of improvement was in areas where training data were collected. In areas where training data were not collected, only the number of pixels whose absolute error was larger than 30% became smaller, though mean absolute error was not improved. The estimation result in this study was better than Global Map-Percent Tree Cover. This also means that the accuracy was high around areas where ground truth data were collected. The pixels where the estimation result was bad were agricultural areas in the south of Vietnam and herbaceous areas in high latitude. One of the reasons is that there are many types of agricultural fields in Southeast Asia in intensity and cropping season. Another reason is that we did not use any training data in water area.

These results suggest that we have to collect more training data throughout continental or global area for estimating the tree cover percentage in global or continental scale. We consider that it is better to use different regression tree models for different areas or land covers. Previous researches have also revealed that the estimate of percent tree cover depended on some factors such as ecoregion, latitude and land covers (Montesano, 2009).

The estimated result of South Asia in 2008 was validated by stratified sampling method. In this validation process, all pixels were grouped into 10 strata by estimated percentage, and random sampling was applied to each stratum. 10 sites were sampled for each stratum. The actual tree cover percentage of sampled pixels was extracted using Google Earth. When there

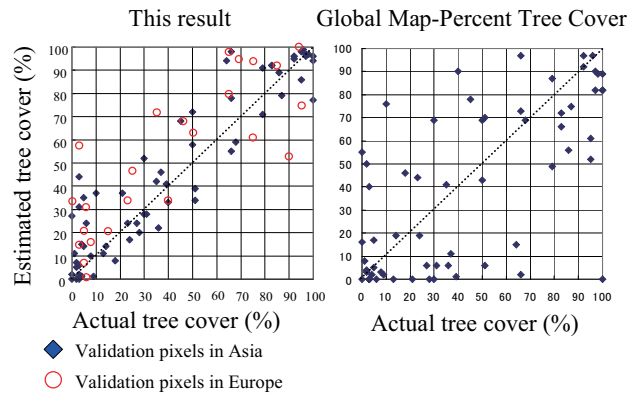


Figure 4. Scatter plot of actual versus estimated tree cover percentage, for this study in left side and for Global Map-Percent Tree Cover in right side. The dashed line indicates a linear 1:1-relationship.

was no high-resolution image or the measurement of tree cover percentage was difficult, random sampling was applied again to that stratum. This validation was conducted for each sampled pixel and for each 3x3 window of pixels centered on each sampled pixel, to deal with the uncertainty in sample location. Pixel-level validation is not accurate when their geo-location is not correct, though this validation is useful when the pixel locations are correct. The result of this validation is illustrated in Figure 5 and shown in Table 3. The root mean square error of estimated tree cover percentage was 17% (mean absolute error = 13%) for single sampled pixels and 13% (mean absolute error = 10%) for 3x3 window of pixels. But this validation method has some problem. First, validation sites can be biased because high-resolution images of Google Earth are limited to the specific areas and land cover types, and the acquisition date of Google Earth images is not always the glowing season. Secondly, it is sometimes difficult to know the exact tree cover percentage from Google Earth or QuickBird images. There were some cases where it was difficult to interpret shadowed areas in forests. They might be on the tree canopy, but might be on gaps between trees. In South Asia, tree cover percentage was overestimated in tea-planted areas and underestimated in mangrove forests.

To compare with previous researches, the results of Global Map-Percent Tree Cover and Vegetation Continuous Fields MOD44B in 2003 (Hansen, 2007) were assessed at the location of 100 sampled pixels used for the validation in South Asia. 13 pixels from among 100 pixels were excluded in this assessment because there was the possibility of mis-registration problem. The result of this assessment is illustrated in Figure 6 and shown in Table 4. It is apparent that each map estimated the tree cover less accurately at intermediate percentage (that is for 31-70%). In this step, it should be noted that tree canopy cover is used as the definition of tree cover percentage in Vegetation Continuous Fields MOD44B. Canopy cover is the crown cover without gap inside crown. It is suggested that the crown cover reasonably correspond with the canopy cover divided by 0.8 (Hansen, 2003). The estimate of this study was better than previous two researches in this region. But this does not necessarily mean that the result of this study was better than other researches. Only the result in areas where training data were collected was better than other researches.

At South Asia and a part of Indonesia, the percent tree cover in 2008 was compared with the result in 2003. The pixels were resampled into a spatial resolution of 0.017986 degrees, corresponding to approximately 2km in this step. The difference of the estimate between 2003 and 2008 arose partly from the actual change of tree cover percentage. But it might have arisen from the difference of data itself or dataset. The dataset in 2003 are different from that in 2008 in resolution, used satellites for the generation of products and the solar zenith angle for producing corrected reflectance using BRDF model. In South Asia, there were pixels in which tree cover percentage changed more than 30% during 5 years (2003-2008). But pixels in which tree cover percentage changed more than 50% were few. The difference of tree cover percentage in this region can somewhat indicate the stability of the estimation result, because there are not so much changed areas in this region. In Indonesia, pixels in which tree cover percentage increased more than 50% were few. But there were a lot of pixels in which tree cover percentage decreased more than 50% (Figure 7). This difference may indicate the actual tree cover change in this region.

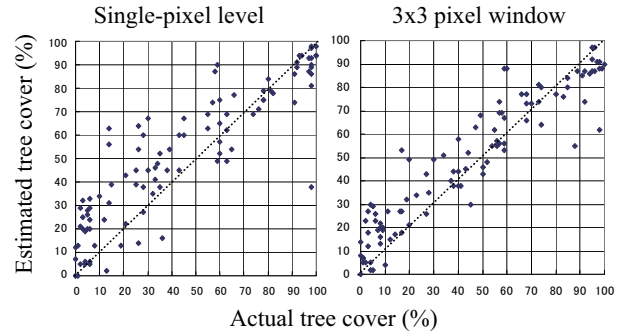


Figure 5. Validation results for estimated tree cover percentage of South Asia in 2008, for each sampled single pixel in left side and for each 3x3-pixel in right side.

Tree cover strata	RMSE (%)	
	Single-pixel level	3x3 pixel window
0-10	4	5
11-20	14	10
21-30	19	17
31-40	26	7
41-50	22	13
51-60	22	17
61-70	25	16
71-80	10	9
81-90	16	14
91-100	4	6
0-100	17	13

Table 3. The root mean square error (RMSE) of estimated tree cover percentage for South Asia in 2008

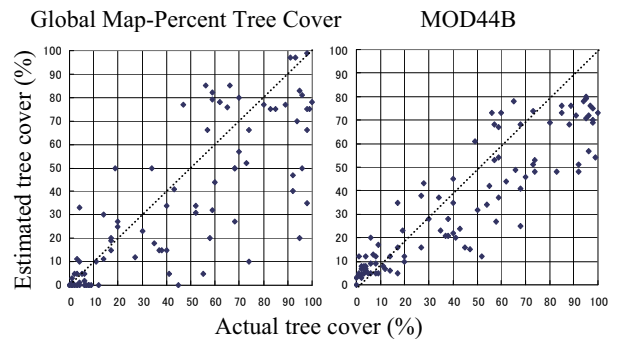


Figure 6. Assessment of the result in Global Map-Percent Tree Cover and Vegetation Continuous Fields MOD44B in 2003

Tree cover strata	RMSE (%)	
	(a)	(b)
0-10	19	5
11-30	26	19
31-50	32	22
51-70	20	24
71-90	18	18
91-100	4	-
0-100	23	18

Table 4. The root mean square error (RMSE) of the result in Global Map-Percent Tree Cover (a) and Vegetation Continuous Fields MOD44B in 2003 (b)

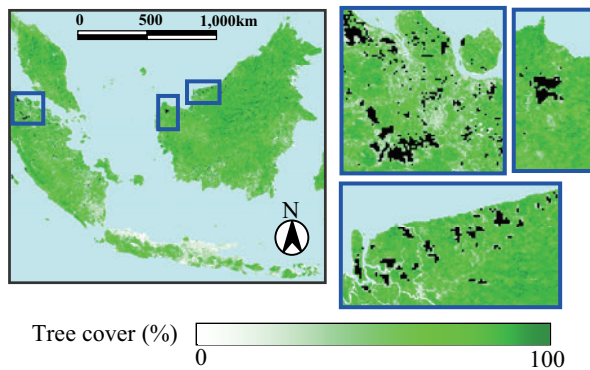


Figure 7. Comparison between 2003 and 2008 in Indonesia. Black pixels indicate areas in which tree cover percentage decreased more than 50% during 5 years. Background image is the tree cover estimation in 2008.

7. CONCLUSIONS

The percent tree cover of some areas in Eurasia was estimated from MODIS data in 2003. In South Asia and a part of Indonesia, the percent tree cover in 2008 was also estimated and compared with the result in 2003. The accuracy of the percent tree cover estimation improved by the use of simulated training data. The result showed the necessity of collecting more training data throughout continental area and constructing regression tree models area by area or depending on land covers to increase the accuracy.

In grasslands, agricultural areas, mangrove forests and tea plantations, the estimation result was sometimes not good because there were some cases where trees could not be clearly distinguished from grasses, shrubs or agricultural areas.

The validation of the estimated result in 2008 was also conducted in South Asia by stratified sampling method. More accurate validation and comparison with previous researches are necessary because this validation has some problems.

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