TREE COVER CLEARANCE MONITORING IN THE PEATLANDS OF INSULAR SOUTHEAST ASIA WITH DUAL POLARIZED SAR DATA

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ABSTRACT: Southeast Asian peatland areas continuously experience extensive tree cover clearance activities both in the form of deforestation of natural forests as well as harvesting of pulp wood plantations (mainly *Acacia*). Monitoring of these changes is important for peatland management purposes. In this paper we present a concept and preliminary tests on tree cover clearance monitoring in peatland areas with a combination of existing land cover map and dual polarized synthetic aperture radar (SAR) data. We highlight the sensitivity of Sentinel-1 C-band VH backscatter to tree cover clearance and utilize simple thresholding in bi-monthly time series analysis to map tree cover clearance within our study areas from May 2015 to June 2016. The detected changes are then overlaid with existing land cover map to separate deforestation of natural forests from tree cover clearance in industrial plantation. The preliminary results indicate that the tested approach will enable frequent and reliable monitoring of plantation harvesting cycles and clearance of natural forest for land cover conversion. However, due to incomplete destruction of forests during forest fires, the total extent of forest areas destroyed by fire activity cannot be accurately derived with the tested method.

1. INTRODUCTION

The peatlands of insular Southeast Asia have experienced dramatic deforestation since 1990 both through accidental fire events and deliberate land conversion to cultivated areas. In 2015, only 29% of the peatlands in Peninsular Malaysia, Sumatra and Borneo remained forested while 27% were covered by industrial plantations (Miettinen et al. 2016). Due to continuing degradation and increasing edge effects, the remaining peat swamp forest areas are increasingly vulnerable to deforestation. Simultaneously, growing areas of peatlands are covered by industrial plantations of wood fibre crops (mainly *Acacia*), with intensive management practices. Therefore, up-to-date monitoring of the changes in tree covered areas is essential for sustainable peatland management. However, in the cloudy conditions of insular Southeast Asia, any operational monitoring activities based on optical data are greatly hampered by severe scarcity of available images. Change detection with optical data may not be viable even on a yearly basis, let alone shorter time frames.

Due to its cloud penetrating capability, Synthetic Aperture Radar (SAR) offers potentially a very powerful tool for land area monitoring in the cloudy conditions of Southeast Asia. Over the past 20 years SAR data has been used for various purposes in insular Southeast Asia ranging from land cover classification (Lee et al. 2002, Langner et al. 2008, Longepe et al. 2011, Dong et al. 2015) and burnt area detection (Liew et al. 1999) to tree crop plantation monitoring (Rosenqvist et al. 1996, Miettinen and Liew 2011, Miettinen et al. 2015) and deforestation monitoring (Sarvision 2011, Whittle et al. 2012, Motohka et al. 2014). Studies analysing deforestation have highlighted the usability of especially the cross-polarized signal for detection of tree clearance (Whittle et al. 2012, Motohka et al. 2014). However, tree cover clearance monitoring is often hampered by the lack of information on the type of woody vegetation cover (natural forest, plantation, shrubland etc.) affected by the change. Without this information, it may not be possible to explain the detected changes and put them in the context of peatland management. Furthermore, until recently, the temporal frequency of the satellite systems may not have been sufficient for reliable tree cover clearance monitoring in the humid tropical conditions where vegetation recovery may be very fast.

In this paper we present a concept and preliminary tests of an approach to monitor tree cover clearance in peatland areas with a combination of existing land cover map (Miettinen et al. 2016) and frequent dual polarized synthetic aperture radar (SAR) data. We take advantage of the Google Earth Engine processing capabilities and their Sentinel-1 dual polarized C-band database, demonstrating the feasibility of a bi-monthly tree cover clearance monitoring approach.

2. MATERIALS AND METHODS

2.1 Study areas

We use two study areas located in Sumatra Island (Figure 1). The first area is located in Riau Province and it covers around 20,828 km^2. The second area is located at the border region between Jambi and South Sumatra Provinces, and covers around 8,919 km^2. The first study area in Riau includes peat swamp forests (PSF) as well as industrial plantations and other land cover types, while the second study area in Jambi and South Sumatra is dominated by forests which experienced significant deforestation by fires in 2015.

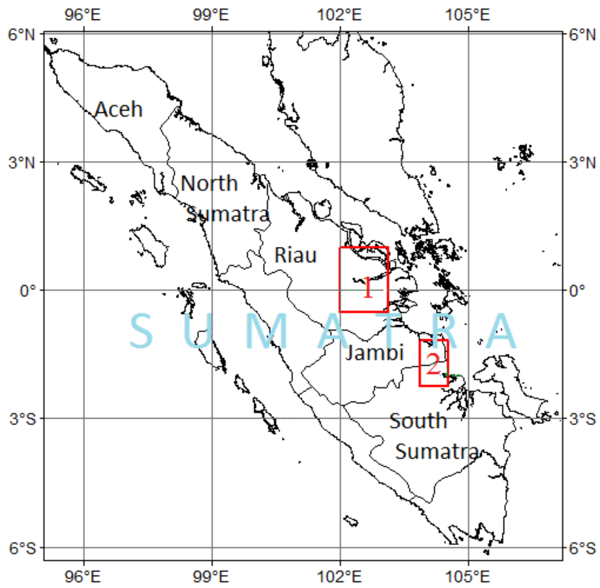

Figure 1. Locations of the two study areas in Sumatra (red rectangles).

2.2 Peatland land cover map

Peatland land cover information published in Miettinen et al. (2016) was used in this study. The mapping was based on visual image interpretation and manual polygon delineation in 1:50 000 - 1:100 000 scale on Landsat 7 and 8 satellite images. The map includes 11 land cover classes (Water, Seasonal water, Pristine PSF, Degraded PSF, Tall shrub/ secondary forest, Ferns/low shrub, Small-holder area, Industrial plantation, Clearance, Built-up and Mangrove) and three different industrial plantation types (oil palm, *Acacia*, and other). The classification was performed only for peatland areas, limiting the scope of this study also only to peatland areas. No land cover map with suitable accuracy and class structure was available for the study areas for mineral soils (i.e. non-peatland areas). For more details of the classification procedure and satellite image dataset used, please refer to the open access article of Miettinen et al. (2016). In this study we concentrate merely on the 'Pristine PSF', 'Degraded PSF' and 'Industrial plantation' areas, aiming to detect tree cover clearance in these land cover types. Furthermore, the two PSF classes are combined into one 'PSF' class.

2.3 Sentinel-1 data

Sentinel-1 dual-polarization C-band Synthetic Aperture Radar (SAR) Ground Resolution Detected (GRD) products available in the Google Earth Engine (see section 2.4) were used in this study. These products have been processed using the Sentinel-1 toolbox and have gone through: 1) thermal noise removal, 2) radiometric calibration, 3) terrain correction using 30 m resolution Shuttle Radar Topographic Mission (SRTM) elevation data and 4) conversion to decibel values. In this study we used all available dual polarization (VV and VH) data acquired on the Interferometric Wide Swath (IW) mode in 10 m spatial resolution during the study period from May 2015 to June 2016.

For the change detection analysis, we created bi-monthly composite images (i.e. data from two months) using the minimum value of all data acquired for a given point during the two months. The minimum value compositing was chosen to ensure detection of possible drop in backscatter values at the earliest occasion. In order to reduce noise, we applied 5x5 pixel median filtering during the time series analysis.

The theoretical repetition time of Sentinel-1 during the study period was 12 days at the equator (with only one satellite, i.e. Sentinel-1A, in operation). However, potentially due to utilization of various acquisition modes, or the fact that the satellite may not have been working fully operationally in the early stages of the study period, only two months compositing period enabled us to get full spatio-temporal coverage of our study areas throughout the entire study period.

2.4 Google Earth Engine (GEE) – Application Programming Interface (API)

The Google Earth Engine is a cloud-based platform for global satellite (and other GIS) data analysis. It provides a vast selection of publicly available remote sensing data (including Sentinel-1 GRD products) stored in Google's servers and enables direct processing of these data in Google's computational infrastructure optimized for parallel processing of geospatial data. For more information please visit https://developers.google.com/earth-engine/. The GEE API is available in both JavaScript and Python. The API supports complex geospatial analyses including e.g. image processing, classification, change detection and vector-based extraction of image statistics. It provides a library of functions which may be applied to imagery for display and analysis. Through the API, users can create their own algorithms and recombine existing algorithms. In this study the GEE API was used to process the bi-monthly composite images used in the analysis, and later to implement the change detection for the study areas between May 2015 and June 2016.

2.5 Data analysis

Altogether 11 sample regions were visually selected within the study areas to collect training data for change detection. Seven of these were selected in the first study area in Riau, including four samples sites (717-978 pixels) in *Acacia* plantations that had been harvested during year 2015 and three unchanged test sites, one each for PSF, Oil palm and *Acacia* (1872-2400 pixels). In the second study area, we selected four sample regions in forest areas, three of them having lost their forest cover in the 2015 fires (1027-3271 pixels) while one retained the forest cover (4501 pixels).

Average changes in the VV and VH backscatter between the bi-monthly composite images within the sample regions were used to derive thresholds for change detection. These thresholds were subsequently used to detect changes in six time steps between the seven bi-monthly composites used in the study: 1) May/Jun 2015, 2) Jul/Aug 2015, 3) Sep/Oct 2015, 4) Nov/Dec 2015, 5) Jan/Feb 2016, 6) Mar/Apr 2016 and 7) May/Jun 2016.

The detected changes were then overlaid on the exiting 2015 land cover map (Miettinen et al. 2016) and all changes outside the interest areas of PSF and industrial plantations on peatland areas are masked out. Finally, minimum thresholds of five and 30 pixels were used for "Clear" and "Possible" changes to mask out noise. (Please see the results section for more details on the different levels of confidence in detected changes.)

3. RESULTS

Figure 2 highlights the changes witnessed in the case of total tree cover clearance (sample regions of *Acacia* 1-4), while the areas retaining tree cover (sample regions PSF, oil palm and *Acacia* 5) maintain their values relatively stable. Note, however the slightly decreasing trend in the PSF, oil palm and *Acacia* 5 study regions which did not experience any tree cover clearance during the study period. The reason for the decreasing trend is unknown. A longer monitoring period is needed to see whether this is a continuing trend or due to some intra- or inter-annual variation.

As seen in Figure 2, the changes in *Acacia* 1 and 4 sample regions happened between Jul/Aug 2015 and Sep/Oct 2015. And clearance of *Acacia* 2 and 4 sample regions occurred between Sep/Oct 2015 and Nov/Dec 2015. The numerical values (in dB) of the changes illustrated in Figure 2 are presented in Table 2. The drops in backscatter values corresponding to tree cover clearances in each sample sites are highlighted in red colour.

The mean VH backscatter drop for the tree cover clearance in the *Acacia* plantation sample sites (i.e. the red values) is 4.19 dB with standard deviation of 0.98. A comparison to VV backscatter changes revealed a much weaker response to tree cover clearance, with an average change of -1.88 dB and standard deviation is 0.63. For this reason, we decided to use the drop in VH backscatter values as an indicator of tree cover clearance.

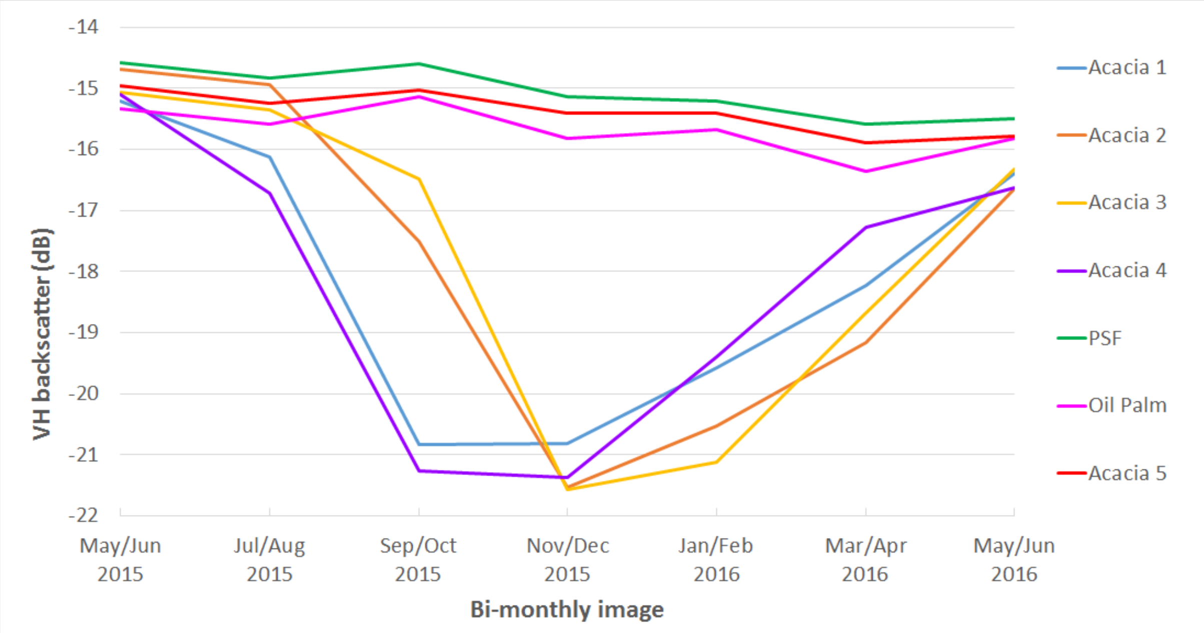

Figure 2. VH backscatter between May/June 2015 and May/Jun 2016 in the Riau study area.

Based on the analysis of the level of the detected changes presented in Table 2 we derived two change detection thresholds: 1) Clear change with a drop of more than 2.50 dB and 2) Possible change with a drop of more than 1.50 dB. These change thresholds can be considered rather strict, minimizing the amount of false detections. Note that the average of the clear changes presented in red colour in Table 2 (i.e. -4.19 dB) plus two times the standard deviation (0.98) would be -2.22 dB. Similarly, the average of the changes due to fire presented in blue colour in Table 2 (i.e. -2.32) plus two times the standard deviation (0.68) would be -0.97. Both of these values are somewhat higher than the actual thresholds used.

The change detection was subsequently run through all of the bi-monthly composites from May/June 2015 to May/June 2016. All drops in VH backscatter larger than 2.5 dB were considered "Clear" changes and all drops between 1.5 dB and 2.5 dB were considered "Possible" changes. If there were two "Possible" changes in two consecutive time steps, they were considered to constitute a "Clear" change. If there were more than one "Clear" change, we recorded only the earliest.

Overall the resulting change maps (example provided in Figure 3) indicate that tree cover clearance (presumably both deforestation and plantation clearance/harvest) can be very well detected in cases of total clearance of the tree cover. However, the forest areas destroyed by fire are much less reliably detected. The "possible" changes do not cover as homogeneous areas as the "clear" changes, but are more spread out and most likely present an incomplete picture of the forest areas destroyed by fire. Please see more discussion on this matter in the discussion section.

Table 2. VH backscatter changes in sample areas (in dB) between May/Jun 2015 and May/Jun 2016.

	Sample region	May/Jun -Jul/Aug	Jul/Aug-Sep/Oct	Sep/Oct-Nov/Dec	Nov/Dec-Jan/Feb	Jan/Feb-Mar/Apr	Mar/Apr-May/Jun
Study area 1	PSF (unchanged)	-0.26	0.23	-0.53	-0.08	-0.37	0.08
	Acacia 5 (unchanged)	-0.30	0.21	-0.37	0.00	-0.50	0.12
	Oil palm (unchanged)	-0.26	0.44	-0.68	0.15	-0.68	0.52
	Acacia change 1	-0.90	-4.72	0.02	1.24	1.35	1.83
	Acacia change 2	-0.25	-2.57	-4.04	1.01	1.37	2.52
	Acacia change 3	-0.29	-1.12	-5.10	0.45	2.45	2.34
	Acacia change 4	-1.62	-4.55	-0.11	1.98	2.12	0.66
Study area 2	PSF (unchanged)	-0.43	0.43	-0.42	0.10	-0.39	-0.13
	Forest fire change 1	-3.51	-2.04	1.54	0.58	-2.11	0.91
	Forest fire change 2	-0.22	-0.40	-2.13	0.76	1.03	-1.35
	Forest fire change 3	-0.57	0.37	-1.81	0.22	-0.52	0.22

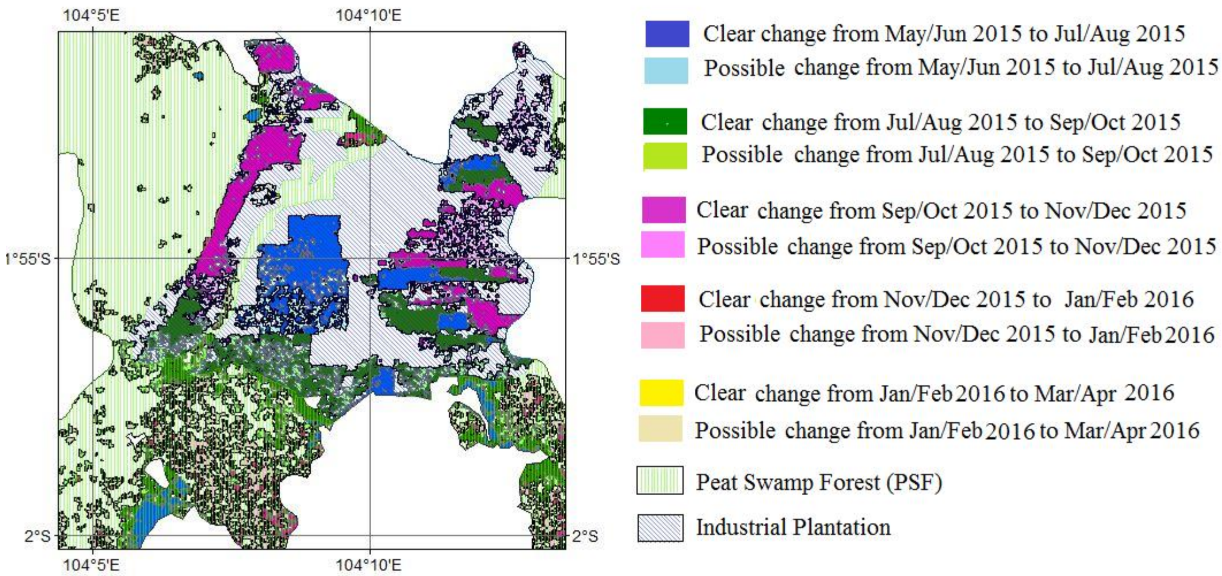

Figure 3. Example of detected tree cover clearance including both clear and possible changes in both peat swamp forest and industrial plantation areas.

4. DISCUSSION AND CONCLUSION

In this paper we have presented the concept and preliminary tests of an approach to monitor tree cover clearance in the peat swamp forests and industrial plantations in the peatlands of Southeast Asia using Sentinel-1 SAR imagery. The combination of up-to-date SAR data together with existing land cover base map allowed interpretation of the detected changes as either deforestation or plantation clearance.

In agreement with earlier studies (Whittle et al. 2012, Motohka et al. 2014), we found that VH backscatter had stronger response to tree cover clearance than VV backscatter. Moreover, the changes in VV backscatter were not consistent, indicating that VV backscatter may also be heavily influenced by issues unrelated to tree cover removal (e.g. wetness of the surveyed area).

Nevertheless, the strong response of VH backscatter to tree cover clearance allowed us to successfully conduct tree cover clearance monitoring in the study area. Although no official accuracy assessment has been done so far, visual examination of the resulting change maps in areas known to the authors indicate high reliability of the detection of total tree cover removal (both deforestation of natural forest for land cover conversion as well as harvesting of a plantation). However, it was also noticed that the destruction of forest by forest fires may not be reliably detectable with this method. This is believed to be due to the varying structure of burnt forest areas, in some cases with high amount of remaining woody debris and standing tree trunks. These remaining structures affect the SAR backscatter values, reducing the change from the pre-fire image to the post-fire image and thereby making change detection less reliable. More tests on larger study areas with wider range of environmental conditions and change types are needed to fully evaluate operational applicability of the tree cover clearance monitoring approach suggested in this paper.

Although the characteristics of the tree cover change monitoring approach are demonstrated here using Sentinel-1 data, the approach is by no means restricted to this source of SAR data. The Advanced Land Observing Satellite-2, Phased Array type L-band Synthetic Aperture Radar ALOS-2 PALSAR-2 data would be at least as useful for this purpose due to potentially even greater suitability of L-band SAR data for tree cover detection.

In this study we needed to use bi-monthly change detection time series in order to get full spatio-temporal coverage of the study area throughout the study period. This may have been due to some incomplete acquisition strategies at the early stages of Sentinel-1. However, currently there are already two Sentinel-1 satellites in orbit (1A and 1B). This reduces the theoretical observation frequency to six days. We therefore believe that in the future this type of tree cover clearance detection could be performed on a monthly basis.

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