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

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ABSTRACT: The natural forests in the peatland of insular Southeast Asia have experienced dramatic deforestation since 1990 by both accidental fire events and deliberate land conversion into cultivated areas. Up-to-date monitoring of the forest clearance is important for sustainable peatland management. Due to very cloudy conditions in the insular Southeast Asia, practical monitoring of forest clearance activities based on optical data are greatly hampered by severe scarcity of cloud free images. With its cloud penetrating capability and relatively high revisiting frequency (12 days repeat cycle), Sentinel-1 synthetic aperture radar (SAR) offers a tool for land cover change monitoring in the cloudy conditions of Southeast Asia. In this paper we present an approach to monitor forest clearance in peatland areas of insular Southeast Asia with Sentinel-1 dual polarized synthetic aperture radar (SAR) data taking advantage of the Google Earth Engine image database and processing capabilities. With this approach, change detection can be performed on a monthly basis. Sample data representing changes caused by deforestation and plantation harvesting in the VV and VH backscatter feature space of Sentinel-1 C-band SAR were collected to obtain the backscattering transition thresholds for forest clearance. These threshold values were used to flag out the potential forest clearance areas in two consecutive time steps. These potential forest clearance areas were then overlaid on a peatland land cover base map crated based on 2015 satellite imageries. All potential change areas intersecting with peat swamp forest or industrial plantations in the base map were marked as forest clearance area. The combination of up-to-date SAR data together with existing forest base map allows interpretation of the detected changes as either deforestation or plantation harvesting. The procedures were run for Sentinel-1 images in 2018 on monthly intervals. We also evaluated the accuracy of the monthly forest clearance in 2018 using Sentinel -2 optical images. The commission error is 22% and omission error 26% for the forest clearance detected by Sentinel-1 images from August 2018 to September 2019 by use of Sentinel-2 data as ground truth.

1. INTRODUCTION

The natural forests in the peatland of insular Southeast Asia have experienced dramatic deforestation since 1990 by both accidental fire activities and deliberate land conversion into cultivated areas. In 2015, only about 29% of the peatlands in Peninsular Malaysia, Sumatra and Borneo still remained peat swamp forest and 27% were covered by industrial plantations (Miettinen et al. 2016). Meanwhile continuing degradation and fire events make the remaining peat swamp forest areas increasingly vulnerable to deforestation. The growing areas of industrial plantations in peatland of South Asia plantations mainly consist of woody fiber crops (Acacia) and Oil Palm, which experienced intensive management practices and fires activities. The clearance of forest could cause environmental and ecological problems. Therefore, up-to-date monitoring of the forest clearance is important for sustainable peatland management. Due to very cloudy conditions in the insular Southeast Asia, practical monitoring of forest clearance activities based on optical data are greatly hampered by severe scarcity of cloud free images.

With its cloud penetrating capability and relatively high revisiting frequency (12 days repeat cycle), Sentinel-1 synthetic aperture radar (SAR) offers a tool for land cover change monitoring in the cloudy conditions of Southeast Asia.

In the past 20 years SAR data has been widely used in insular Southeast Asia for various purposes such as land cover classification (Lee et al. 2002, Langner et al. 2008, Dong et al. 2015), burnt area detection (Liew et al. 1999), tree crop plantation monitoring (Miettinen and Liew 2011, Miettinen et al. 2015) and deforestation monitoring (Sarvision 2011, Whittle et al. 2012, Motohka et al. 2014). Studies on analysing deforestation have proven the usability of the cross-polarized signal for detection of tree clearance (Whittle et al. 2012, Motohka et al. 2014, Shi et al. 2016).

In this paper we present an approach to monitor forest clearance in peatland areas of insular Southeast Asia with Sentinel-1 dual polarized synthetic aperture radar (SAR) data taking advantage of the Google Earth Engine image database and processing capabilities. With this approach, change detection can be performed on a monthly basis. The combination of up-to-date SAR data together with existing forest base map allows interpretation of the detected changes as either deforestation or plantation harvesting. We also evaluated the accuracy of the monthly forest clearance in 2018 using Sentinel-2 optical images. The commission error was 22% and the omission error was 26% for the monthly forest clearance map from August 2018 to September 2018, using Sentinel-2 data as ground truth.

2. MATERIALS AND METHODS

2.1 Study areas

We used two study areas in Sumatra Island (Figure 1). The first study area is located in Riau Province and it covers around 15,586 km^2. The second area is sited at the border region between Jambi and South Sumatra Provinces, and covers around19,936 km^2. The first study area includes peat swamp forests (PSF) as well as industrial plantations and other land cover types, while the second study area is dominated by forests.

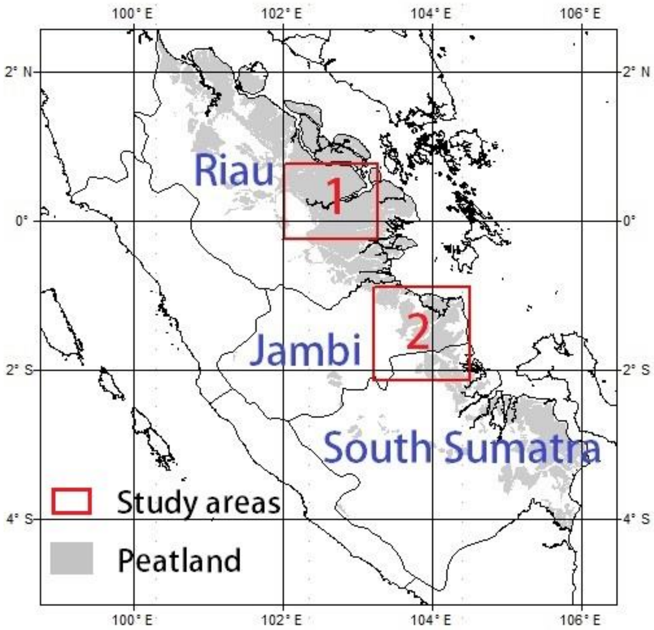

Figure 1. Locations of the two study areas in Sumatra (red rectangles)

2.2 Peatland land cover map

Peatland land cover information in Miettinen et al. (2016) was used in this study. The map was created based on visual image interpretation and manual polygon delineation in 1:50 000 - 1:100 000 scale using 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). In this study we group the 11 classes into 3 simplified classes: Peat swamp forest (PSF), Industrial plantation and Other. By this way we limited the forest clearance to only in these "Forest" area.

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 2.5) were used in this study. These products have been processed using the Sentinel-1 toolbox. In this study we used all VV and VH dual polarization data acquired on the Interferometric Wide Swath (IW) mode in 10 m spatial resolution in year 2018.

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

2.4 Sentinel-2 data

Sentinel-2 is an Earth observation mission from the EU Copernicus Programme that systematically acquires optical imagery at high spatial resolution (10 m to 60 m) over land and coastal waters. The mission is a constellation with two twin satellites (Sentinel-2A and Sentinel-2B). Sentinel-2 Multi-spectral data have 13 bands in the visible, near infrared, and short wave infrared part of the spectrum. In this study we used 10 m resolution band 4 (red) and band 8 (NIR) as well as 20 m resolution band12 (SWIR) to create false colour images for accuracy assessment purpose. (see section 2.7)

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

The Google Earth Engine (GEE) 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. The GEE API allows complex geospatial analyses including e.g. image processing, classification, change detection and visualization. Through the API, users can also create their own algorithms and recombine existing algorithms. In this study the GEE API was used to create the monthly minimum composite images in 2018, and later to implement the forest clearance algorithm to generate the forest clearance map for 2018. We also GEE to create the cloud free composite image for the month of July 2018 to be used later in accuracy assessment.

2.6 Data analysis

Altogether 22 sample regions were visually selected within the 2 study areas to collect training data for change detection. 11 of these samples were selected in the first study area, including four sites (1015-3870 pixels) in *Acacia* plantations that had been harvested during year 2018 and three unchanged test sites, one each for PSF, Oil palm and *Acacia* (2050-19520 pixels). In the second study area, all 11 sample regions were selected in forest areas, ten of them having lost their forest cover during the year 2018 (425-5076 pixels) while one retained the forest (2654 pixels). The information of the samples is shown as Table 1.

Table 1. Information of samples

Study area	Sample region	Land cover	Size (in pixels)	Land cover change (Yes/No)
Study area1	Site1	Acacia 1	4152	No
	Site2	Oil Palm 1	19520	No
	Site3	PFS	4050	No
	Site5	Oil Palm 2	2545	Yes
	Site6	Oil Palm 3	1463	Yes
	Site4	Acacia 2	2940	Yes
	Site7	Acacia 3	1015	Yes
	Site8	Acacia 4	1028	Yes
	Site9	Acacia 5	2103	Yes
	Site10	Acacia 6	2436	Yes
	Site11	Acacia 7	3870	Yes
Study area2	Site1	PSF1	2654	No
	Site2	PSF2	5076	Yes
	Site3	PSF3	723	Yes
	Site4	PSF4	1519	Yes
	Site5	PSF5	2126	Yes
	Site6	PSF6	425	Yes
	Site7	PSF7	2161	Yes
	Site8	PSF8	900	Yes
	Site9	PSF9	860	Yes
	Site10	PSF10	1056	Yes
	Site11	PSF11	547	Yes

Average changes in the VV and VH backscatter between two consecutive monthly minimum composite images in 2018 within the sample regions were used to derive thresholds for change detection. These threshold values were used to flag out the potential forest clearance areas in two consecutive time steps. These potential forest clearance areas were then overlaid on a peatland land cover base map crated based on 2015 satellite imageries. All potential change areas intersecting with peat swamp forest or industrial plantations in the base map were marked as forest clearance area. Finally, minimum thresholds of 500 pixels (0.05 km^2) were used to mask out noise.

Flow chart of data analysis is illustrated in Figure 2.

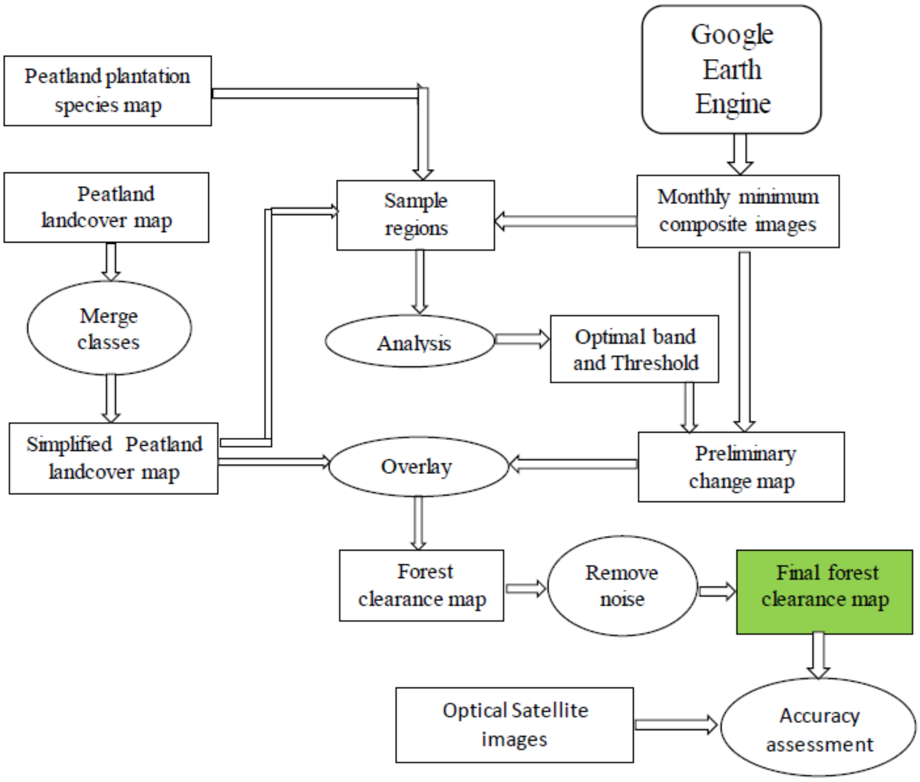

Figure 2. Flow chart of data analysis

2.7 Accuracy assessment

A region of 0.5 X 0.5 degree (5568 X 5532 pixels) in study area 1 was chosen for accuracy assessment. We assessed the monthly change detected from August 2018 to September 2018. The Sentinel-2 cloud free composite image of July 2018 was created using GEE as the image before change and the Image acquired in September 30, 2018 was downloaded as the image after change. NDVI were calculated for both images. All pixels with NVDI greater than 0.5 in July 2018 composite image and NDVI smaller than 0.4 in 30-Sep-2018 image (excluding cloudy area) were considered as forest clearance. The salt-and-pepper noise was masked out and the resulting image was overlaid on 2015 forest base map to exclude non-forest area. Resulting forest clearance image was finally used as ground truth to evaluate the accuracy of our monthly forest clearance result detected by sentinel-1.

3. RESULTS

Figure 3 shows the VH backscatter time series in the training sites in Study Area 1. It highlights the forest clearance taking place in year 2018 in sample regions of *Acacia 2 to 6, Oil Palm 2* and *Oil Palm 3*; while the unchanged forest/plantation (sample regions *PSF, Oil Palm 1* and *Acacia* 1) sites maintain their relatively stable values. The biggest drop in VH backscatter happened in *Acacia 4* during August to September 2018; the VH backscatter drops in *Acacia* 2 and 6 happened during May to June 2018. The VH backscatter drops in *oil Palm* 2 and 3 happened during July to August and September to October 2018 respectively. The numerical values (in dB) of the changes illustrated in Figure 3 are presented in Table 2. The drops in backscatter values corresponding to forest clearances in each sample sites are highlighted in red colour.

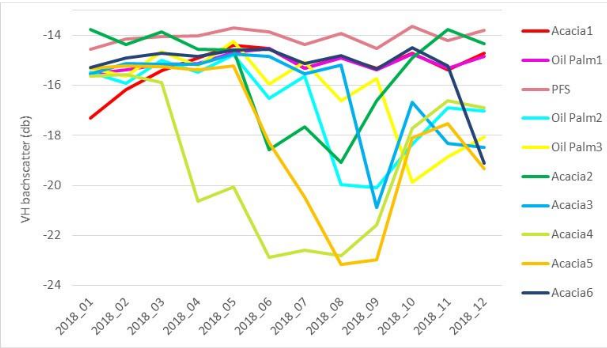

Figure 3. Monthly VH backscatter in year 2018 in the Riau study area.

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

Study area	Change	Sample region	Jan-Feb	Feb-Mar	Mar-Apr	Apr-May	May-Jun	Jun-Jul	Jul-Aug	Aug-Sep	Sep-Oct	Oct-Nov	Nov-Dec
Study area1	No	Acacia1	1.14	0.76	0.51	0.52	-0.13	-0.78	0.44	-0.45	0.60	-0.67	0.68
		Oil Palm1	0.13	0.23	0.05	0.42	0.17	-0.80	0.42	-0.46	0.62	-0.56	0.47
		PSF	0.42	0.09	0.03	0.33	-0.15	-0.52	0.46	-0.61	0.89	-0.58	0.42
	Yes	Oil Palm2	-0.45	0.91	-0.50	0.70	-1.74	0.89	-4.32	-0.13	1.74	1.47	-0.12
		Oil Palm3	-0.34	0.99	-0.56	0.97	-1.71	0.90	-1.55	0.87	-4.15	1.03	0.78
		Acacia2	-0.59	0.49	-0.68	-0.03	-3.98	0.89	-1.41	2.45	1.70	1.15	-0.57
		Acacia3	-0.26	-4.82	-0.99	0.08	0.46	1.29	0.85	1.36	2.01	-0.07	0.07
		Acacia4	0.42	-0.04	-0.01	0.42	-0.09	-0.70	0.36	-5.70	4.22	-1.66	-0.14
		Acacia5	0.08	-0.32	-4.74	0.56	-2.80	0.29	-0.24	1.25	3.83	1.12	-0.28
		Acacia6	0.10	-0.02	-0.12	0.14	-3.07	-2.17	-2.68	0.19	4.85	0.57	-1.79
		Acacia7	0.39	0.17	-0.12	0.26	0.02	-0.56	0.33	-0.55	0.85	-0.70	-3.89
Study area2	No	PSF1	0.46	-0.12	0.20	-0.01	-0.03	-0.69	0.62	-0.60	0.51	-0.47	0.70
	Yes	PSF2	0.23	-0.09	0.66	-0.19	0.10	-0.99	0.59	-5.73	1.60	1.68	1.00
		PSF3	0.49	0.05	0.07	0.17	-0.12	-0.92	0.83	-3.15	2.34	-0.01	0.81
		PSF4	-0.65	-0.65	4.06	-3.15	-0.14	-1.15	1.49	-0.23	1.46	0.16	1.49
		PSF5	0.91	-1.87	0.31	-0.67	1.80	-0.75	0.59	-0.46	1.25	-3.15	-0.29
		PSF6	0.57	-0.06	-0.07	0.18	-0.17	-3.39	1.54	-0.32	1.89	-0.18	0.61
		PSF7	0.97	-4.91	5.07	0.24	-0.11	-1.02	0.49	-0.41	0.77	-0.55	0.52
		PSF8	0.52	-0.38	0.38	0.33	-0.36	-0.82	0.08	-3.23	1.63	0.11	1.75
		PSF9	0.61	-3.95	4.17	-0.18	-0.28	0.05	-0.16	0.11	-0.04	0.29	-0.39
		PSF10	0.19	-0.07	0.80	-0.80	-0.16	-1.08	0.90	-3.08	1.08	0.63	0.54
		PSF11	0.36	0.51	-0.34	0.27	0.07	-1.27	-2.76	-0.88	1.19	2.37	0.30

The mean VH backscatter drop for the forest clearance in the study area 1 sample sites (i.e. Industrial Plantations) is 4.29 dB with standard deviation of 0.87. In comparison, the VV backscatter change is much weaker in response to forest clearance, with an average drop is 1.98 dB with standard deviation of 0.65. For this reason, we decided to use the drop in VH backscatter values as an indicator of tree cover clearance. The mean VH backscatter drop for the forest clearance in the study area 2 sample sites (i.e. Peat Swamp Forest) is 3.75 dB with standard deviation of 0.95.

Based on the analysis of all samples of the detected changes presented in Table 3, a drop of 2.0 dB in VH backscatter is determined to be the detection threshold for tree cover clearance. This value is the average of the change magnutides presented in red in Table 2 (i.e. 3.93 dB) reduced by two standard deviations.

Change detection was run through all of the monthly composites for the 12 months of 2018. All drops in VH backscatter larger than 2.0 dB were considered forest clearance area. If there were more than one clearance, the later one would overwrite the earlier one in the yearly forest clearance map.

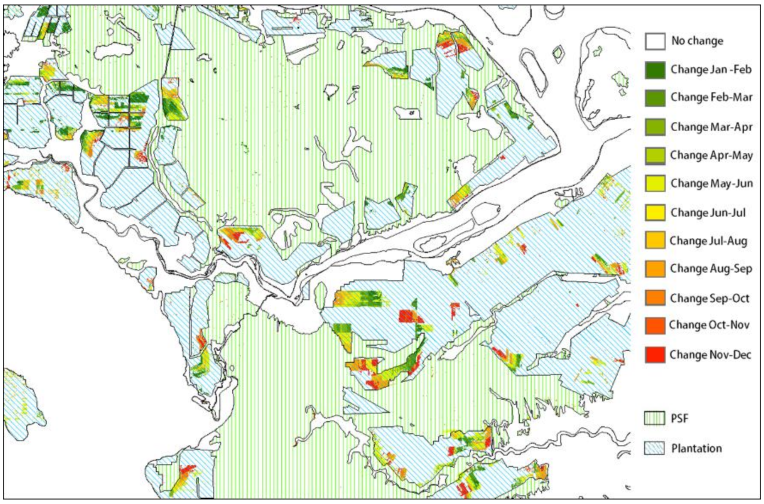

Figure 4. An example of detected forest clearance in both peat swamp forests and industrial plantations.

Figure 4 shows an example of forest change map produced using the VH backscatter change detection method. Overall, forest clearance (both deforestation and plantation clearance/harvest) can be very well detected. However, the forest areas destroyed by fire are less reliably detected than plantation clearance/harvest. In study area 2, the change in peatswamp forest was mainly by fires during the study period. It is observed that the drop of average VH backscatter in study area 2 is smaller than in study area 1, but the standard deviation is higher. This may be due to the less homogeneity of the change areas in peat swamp forest compared to that in Industrial Plantations, Thus, the peatswamp forest area destroyed by fires may be underestimated.

The accuracy of the monthly forest clearance in 2018 was evaluated using Sentinel-2 optical images. Because of the scarcity of cloud free images, only the change map for August to September 2018 was evaluated. The accuracy assessment is presented in Table 3. Using forest clearance map created using Sentinel-2 data as the ground truth, the commission error and omission error of the monthly forest clearance map from the Sentinel-1 data using our approach are 33.0% and 29.6% respectively.

Table 3 Accuracy assessment of the August to September change map

		Forest clearance detected by Sentinel-1 (pixels)		
		Yes	No	Total
Forest clearance detected by Sentinel-2 (pixels) (Ground truth)	Yes	95 153	40 012	135 165
	No	46 817	30 620 194	30 667 011
	Total	141 970	30 660 206	30 802 176

Commission Error = 46817/141970 = 33.0%
Omission Error = 40012/135165 = 29.6%
Kappa index = 0.685

4. DISCUSSION AND CONCLUSION

In this paper we implemented a change detection approach to monitor forest clearance in 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 the detection of changes as either deforestation or plantation clearance. With its cloud penetrating capability and relatively high revisiting frequency (12 days repeat cycle), Sentinel-1 SAR data enable forest clearance change monitoring on a monthly basis in the cloudy conditions of Southeast Asia.

In this study we found that VH backscatter had stronger response to forest clearance than VV backscatter. This is in agreement with earlier studies (Whittle et al. 2012, Motohka et al. 2014, Shi et al. 2016). Moreover, the changes in VV backscatter were not consistent because VV backscatter may be heavily influenced by other factors that are unrelated to forest clearance such as the wetness of the sample area.

Our study shows that the strong response of VH backscatter to land cover change allows us to conduct forest clearance monitoring. Accuracy assessment is conducted by use of optical satellite imagery as ground truth. The commission error was 33% and the omission error was 29.6% for one of the forest clearance maps assessed.

It should be noticed that forest clearance detection from the destruction of forest by fires maybe less reliable using this approach. This may be due to the inhomogeneity in the burned areas. In some cases, there may be remaining woody debris and standing tree trunks that could increase the SAR backscatter. Hence, the drop in VH backscatter may be reduced resulting in increased omission error.

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