ANALYSIS OF MULTI-MODE PALSAR DATA TO DETECT FOREST DEGRADATION IN THE HUMID TROPICS

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ABSTRACT

Selective logging is applied throughout the tropics causing high levels of forest degradation. Sustainable forest management has the potential to conserve biomass but is not widely applied in the field. Reduced impact logging can promote sustainable forestry but for that sake the degradation stage of a forest must be evaluated. Given a certain forest type, above-ground biomass values can be deduced from that data. Due to the limitation of any kind of satellite sensor to directly measure the biomass especially in complex and carbon-dense ecosystems such as the humid tropics, we analyzed the application of ALOS PALSAR multi-mode L-band radar data to what extent canopy openings can be detected, which describe the degradation stage of a forest. Such information can then be used to deduce the above-ground biomass. In comparison to optical data, which are hampered by the frequent cloud cover in the tropics, radar sensors have the great advantage to derive data irrespective of weather conditions. In this study, Phased Array type L-band Synthetic Aperture Radar (PALSAR) level 1.5 data with 12.5m spatial resolution, 34.3 degree incidence angle and HH-HV polarization were analyzed for the purpose of forest degradation monitoring. For that sake, the different polarization modes were compared with each other. Study site was a production forest in Sabah, Malaysian Borneo. High resolution optical data from the Advanced Visible and Near Infrared Radiometer type 2 (AVNIR-2) and the Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM) sensor onboard the ALOS platform in combination with ground-truth data were used to validate the PALSAR data. Our results showed that in comparison to the HH data, the HV band shows a higher accuracy in separating degraded forests from pristine forests. In the HV polarization mode it was possible to distinguish highly degraded secondary forests with an open crown cover dominated by regrowth from pristine forests but it turned out that a separation of forests, which have been degraded using conventional selective logging techniques – the prevailing logging type in Borneo – was not feasible. Another limitation was caused by foreshortening and radar shadowing due to hilly terrain. Summarizing, it has to be stated that HV polarized L-band data from the PALSAR sensor can be used to screen for degradation processes occurring before forest conversion, but are too restricted to distinguish between pristine and conventionally logged-over forests. However, the application of PALSAR L-band data in combination with other sensor data, such as for example AVNIR-2 seems to be a very promising approach.

Keywords: ALOS, PALSAR, L-band, forest degradation, multi-mode, biomass, Borneo, tropics

1. INTRODUCTION

Pressure on tropical forests – especially in SE-Asia - increased tremendously in the past two decades [1, 2]. Most of forests on Borneo are permanent forest estates and have been commercially selectively logged more than twice [3]. Selective logging can destroy more than half of all trees within a forest, mainly because it causes a lot of collateral damage to the surrounding vegetation due to the unrestricted use of heavy machinery [4]. Therefore there is a high pressure on these forests due to deforestation and forest degradation processes. Sustainable forest management in combination with reduced impact logging and longer cutting cycles has the potential to conserve biomass due to the reduction of the physical impact on the ground by applying a combination of pre-harvest census, controlled felling and skidding, lowered allowable cut, and regulated machinery use [5, 6]. However, it is not widely used mainly due to the seemingly higher management costs [7]. International frameworks such as reducing emissions from deforestation and degradation (REDD+) can promote sustainable forestry, but for that sake it must be possible to do transparent and repeatable measurements of the degradation stage of a forest [3], which also reflects its above-ground biomass.

Satellite remote sensing offers the best approach to cover large and inaccessible areas of forests [8]. Except for light detection and ranging (LiDAR) systems, all other sensors face problems due to sensor saturation at lower than the actual biomass values when applying in the humid tropics. Also the detection for forest degradation in comparison to deforestation processes is much more challenging [9]. Reason for this is the fact that these forests are very complex and carbon-dense ecosystems [10] with elevated biomass rates up to 500t C/ha and above. However, in comparison to optical data, which are limited by atmospheric effects such as clouds, haze (which are frequent in the humid tropics) as well as their resulting shadows, radar data has the advantage to be able to obtain data during day- and night-times, irrespective of the atmospheric conditions [11]. This is very crucial as it will be of utmost importance under REDD+ to be able to derive the degradation stages of a forest at specific periods of time and the frequent cloud coverage of the humid tropics can severely restrict the application of optical sensor data. However, additional to sensor saturation, radar data shows limitations over mountainous terrain due to foreshortening and radar shadowing artifacts [12, 13].

Excluding artifacts due to a heterogenic topography, we analyzed a comparable flat area of lowland mixed dipterocarp forest in Sabah, Malaysian Borneo. In our study we analyzed to what extent multi-mode PALSAR data is able to detect forest degradation in the humid tropics, thereby comparing HH and HV polarization modes. We analyzed to what extent canopy openings can be detected, which describe the degradation stage of a forest and can therefore be used to finally deduce the above-ground biomass of a specific forest type.

2. METHODS

2.1 Study area

For the investigation of multi-mode PALSAR data for forest degradation monitoring in the humid tropics, we investigated a production forest in Sabah, Malaysian Borneo. The climate of that region is characterized by high temperatures with frequent rainfall over the whole year. As study area two subsets at the southwestern border of the Tangkulap forest reserve (one within a protected area inside the forest reserve as reference for good forest quality and one outside the forest reserve in an area, which is in process of conversion to a plantation) with a total area of slightly more than 203 ha were chosen. The prevailing forest type is mixed lowland dipterocarp forest with varying levels of forest degradation.

Tangkulap was licensed for logging in 1970 using conventional logging practices, and since 2002 all logging activities were stopped [14]. The study area was chosen to account for different degradation stages within the same forest type, thereby combining pristine areas of lowland dipterocarp forest (northern subset of the study area) as well as areas of varying forest degradation due to the establishment of a plantation area outside the southwestern end of the Tangkulap forest reserve (southern part of the study area; Fig. 1).

Fig. 1 Landsat ETM+ scene of 2007-05-26, showing the geographic position of the study areas, which are situated within the white rectangle at the southwestern border of the Tangkulap forest reserve (Sabah, Malaysian Borneo)

While most of the surrounding area shows a highly heterogeneous topography with a lot of small-scale slopes, the study area itself is characterized only by a slightly undulating topography (Fig. 2). The reason for this restriction on relatively flat areas was to best avoid artifacts due to foreshortening and radar shadowing.

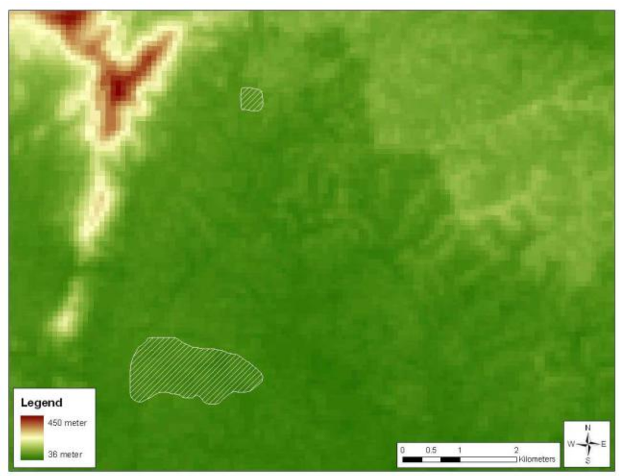

Fig. 2 Enlargement of rectangle of Fig.1 showing the study areas superimposed on a topographic map (SRTM dataset)

2.2 Satellite data

All ALOS sensors were combined in this study. While geocoded 2.5m high resolution ALOS PRISM nadir data in combination with ground-truth data from field surveys were used to identify the crown cover conditions (Fig. 3), 10m ALOS AVNIR-2 data was classified to derive 10 different forest degradation levels.

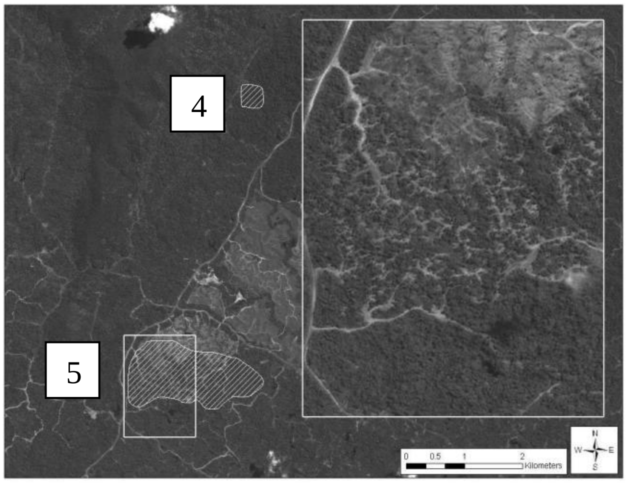

Fig. 3 ALOS PRISM scene (2008-05-21) showing the crown cover closure of the forests within both study areas with an enlarged subset (white rectangle). The northern part of the study area (number referring to Fig. 4) shows pristine forest cover in comparison to the southern part of the study area (number referring to Fig. 5) with various degrees of forest degradation

All optical ALOS data was acquired on the same day in 2008-05-21. As the field survey was undertaken two years later in June 2010 and the forest condition might have slightly changed (Fig. 4-5), the main focus was put on the high resolution PRISM data for crown cover identification.

Fig. 4 Picture taken in June 2010 during a helicopter flight over the pristine forests of the northern part of the study area (see Fig. 3 for geographic position)

Fig. 5 Picture taken in June 2010 during a helicopter flight over the forests of the southern part of the study area (see Fig. 3 for geographic position) with varying levels of forest degradation

The ALOS PALSAR data was acquired one month later on June 26, 2008. Geocoded PALSAR level 1.5 data with a 12.5m spatial resolution, 34.3 degree incidence angle and HH-HV polarization was analyzed.
In addition, Shuttle Radar Topography Mission (SRTM) data were used in order to visually screen for subset areas with a flat topography (Fig. 2) in order to avoid artifacts due to foreshortening and radar shadowing.

2.3 Classification of ALOS AVNIR-2 data

In a first step it was necessary to derive some kind of ground-truth dataset, showing various forest degradation classes, against which the PALSAR data could be tested. For that sake the following band combination of the red (610-690nm) and the near infrared (760-890nm) bands of the AVNIR-2 sensor were used:

Degradation stage = 1/(red * NIR)

According to our analysis this band combination combines two different aspects of a forest. On the one side the red band represents the soil component, thus the openness or closeness of the crown cover. On the other side shows the near infrared band the vegetation status regarding age and health condition.
The degradation stage or crown cover and forest status (CCFS) index was further equally split into 10 different forest degradation classes using a decision tree approach. The resulting classes ranged from 1 (pristine) over 5 (more than 50% of the canopy opened) to 10 (clear cut area). PRISM data as well as ground-truth data were used

to help to identify and cross-check the crown cover conditions as detected by this algorithm. A regression analysis against measurements on the ground was used to analyze the accuracy of this approach.

2.4 Preprocessing of the PALSAR data

The radiometry of the PALSAR data was converted to amplitude data and its geolocation adjusted to fit the AVNIR-2 scene as ground-truth data revealed the high accuracy of the AVNIR-2 dataset. No filtering for speckle removal was performed of the PALSAR data as it would have influenced the signal of the backscatter data (Fig. 6).

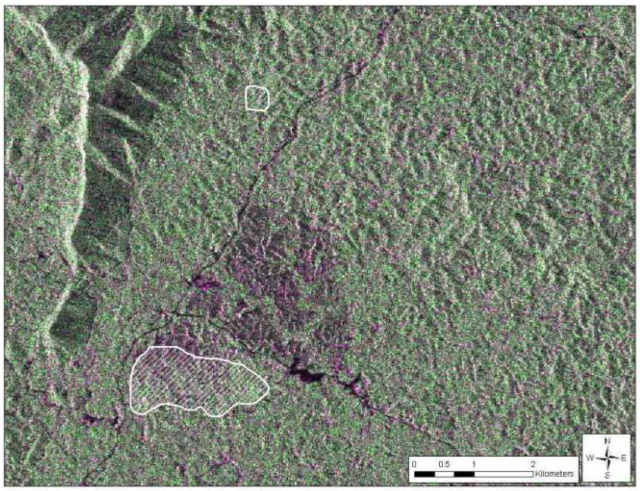

Fig. 6 ALOS PALSAR scene from 2008-06-26 (HH, HV, HH polarization). Clearly visible are the artifacts caused especially by foreshortening due to the heterogenic topography in the western but also in the eastern parts next to the study areas

2.5 Analysis of PALSAR data

The backscatter of both PALSAR polarization modes was analyzed based on 10 different forest degradation classes. In order to investigate the suitability of the different polarizations (HH against HV) to significantly separate different forest degradation stages in the humid tropics, an Independent-Samples T-test was used. With this test, the mean backscatter value of the pristine forest class was tested against the mean backscatter values of all other forest degradation classes, thereby comparing both polarization modes with each other.

3. RESULTS

3.1 Forest degradation stages according to AVNIR-2

Based on the AVNIR-2 imagery from 2008-05-21 a forest degradation map of the study area was derived. This dataset was equally split into 10 degradation classes. As it happened, forests of the degradation stage 2 did not occur in our study area. Table 1 gives an overview of the areas of the different forest degradation stages of our study sites.

Table 1 Forest degradation classes from 1 (pristine) to 10 (clear cut area) and their areas in ha

Forest degradation class	Area
1 (Pristine forest)	5.0 ha
2 (Medium density forest; closed canopy)	0 ha
3 (Medium density forest; open canopy)	12.1 ha
4 (Low density forest; open canopy)	26.1 ha
5 (Highly degraded sec. forest; open canopy)	42.5 ha
6 (Highly degraded land; smaller trees, bushes)	44.6 ha
7 (Dense bushes and shrubs)	31.5 ha
8 (Open bushes and shrubs)	26.4 ha
9 (Clear cut area with small bushes)	13.8 ha
10 (Clear cut area with bare soil)	1.3 ha

The spatial distribution of the single degradation classes is displayed in Fig. 7. It is clearly visible that most of the forests with the lower degradation levels can be found in the northern part of the study area, while the higher degradation stage are situated in the southern part due to the establishment of a plantation area.

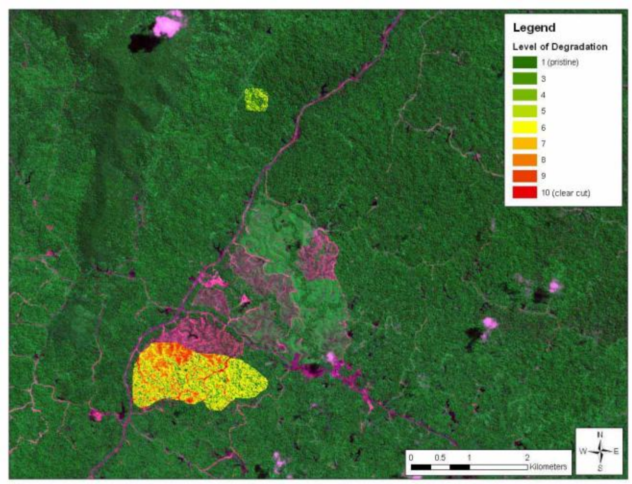

Fig. 7 ALOS AVNIR-2 scene from 2008-05-21. This scene was classified into 10 degradation levels ranging from 1 (pristine forest) to 10 (clear cut area)

A regression analysis against 22 permanent sample plots on the ground within the Tangkulap forest reserve revealed a good correlation of the degradation stage index with an R^2 of 0.47.

3.2 Comparison of PALSAR polarization modes

In this research the ability of the different polarization modes of the PALSAR sensor to discriminate various forest degradation stages in the humid tropics was analyzed. The results of this analysis are visualized in boxplot graphs with the mean backscatter values of each polarization mode displayed on the ordinate and the different forest degradation stages from 1 (pristine forest) to 10 (clear cut area) on the abscissa. In this study the mean backscatter of the undisturbed forest class (1) was compared to the mean backscatter of the other classes with varying forest degradation. As our study area did not include forests of the degradation class 2, which represents medium density lowland forest with a still closed canopy cover, only the degradation classes 3-10 could be analyzed. The orange arrows mark the degradation classes, which can be discriminated from undisturbed forest at a significance level of 0.05.

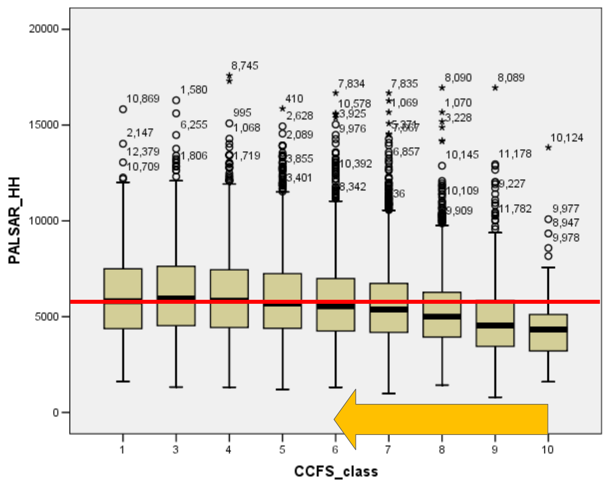

Fig. 8 Boxplot of the mean backscatter value within each forest degradation class for HH polarization. Yellow arrow marks classes, which can be discriminated from pristine forest (1)

Fig. 8 shows the result of the PALSAR HH polarized data. HH data managed to distinguish vegetation types 10 (clear cut areas) to 6 (highly degraded land with smaller trees but mainly dominated by shrubs and bushes) from pristine forests.

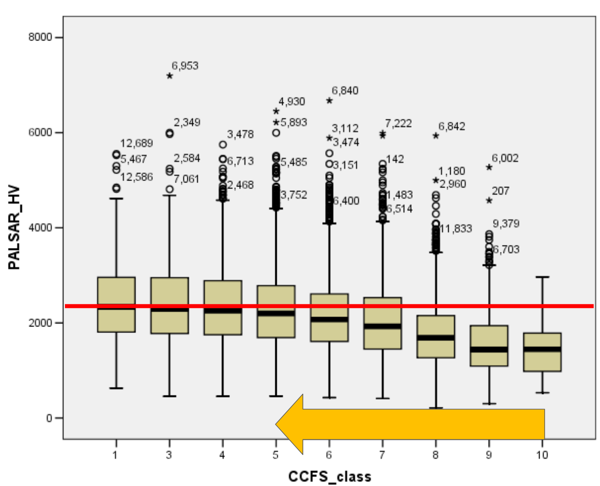

Fig. 9 Boxplot of the mean backscatter value within each forest degradation class for HV polarization. Yellow arrow marks classes, which can be discriminated from pristine forest (1)

HV-polarized data on the other hand performed slightly better and was able to separate even highly degraded secondary forests with an open crown cover dominated by regrowth from pristine forests (Fig. 9). However, forest types with a lower degradation stage could not be significantly separated from pristine forests.

4. DISCUSSION AND CONCLUSION

The tropical forests in SE-Asia are highly threatened not only by deforestation processes but also to a large extent by forest degradation due to selective logging [3]. International frameworks such as REDD+ can help to replace unsustainable conventional logging techniques with more sustainable reduced-impact logging and other sustainable forest management techniques. However, for the implementation of REDD+ it is crucially important to be able to monitor forest degradation. Such information can then be used to derive above-ground biomass estimates. This is quite challenging due to the complexity of tropical forests as well as the elevated above-ground biomass values of these ecosystems [10].

In this study we compared the suitability of different polarization modes of L-band PALSAR level 1.5 data with 12.5m spatial resolution and 34.3 degree incidence angle to detect forest degradation in the humid tropics. To avoid the well-known limitations of radar data over hilly terrain [12] causing foreshortening and radar shadowing effects, a relatively flat study area was chosen. Even though a detailed discrimination of different forest degradation classes was not feasible with both datasets it has to be stated that HV polarized data performed slightly better than data with HH polarization. While HH polarized data was able to distinguish highly degraded land that is mainly dominated by smaller trees, shrubs and bushes (degradation level 6) from pristine forests, HV data allowed to even separate one lower degradation level (level 5 of our classification scale: highly degraded secondary forests with an open crown cover dominated by regrowth). This degradation type is mainly found in forests, which are in process of conversion to plantation or agricultural areas, such as in the southern part of the study site outside the Tangkulap forest reserve. However, it is less characteristic for the conventionally logged forests of Borneo, even though such forests also show high levels of forest degradation.

Therefore, it was not possible to use ALOS PALSAR data with above configurations to investigate forest degradation processes that occur in a formerly conventionally logged production forest because the resulting level of forest degradation, even though high, could not be separated from pristine forests. But our analysis revealed that it is possible to distinguish pristine forests from much degraded secondary forests with an

open crown cover dominated by regrowth when using HV polarized data, which allows a screening for severe forest degradation events in the tropics, which often occur prior to land conversions.
Summarizing it has to be stated that while optical data have the advantage to better differentiate between various land and vegetation classes [2, 15], and thus also better discriminate different forest degradation classes, the great advantage of radar data is to obtain imageries irrespective of the atmospheric conditions, which hamper optical sensor systems [11]. This allows obtaining forest cover information at regular time intervals. A combination of ALOS PALSAR HV polarized data with optical sensors such as AVNIR-2 might therefore be a promising approach to operationally measure forest degradation processes in the tropics.

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