Mapping palm oil expansion using SAR to study the impact on the CO₂ cycle

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Abstract. With Malaysia being the second largest palm oil producer in the world and the fact that palm oil ranks first in vegetable oil production on the world market the palm oil industry became an important factor in the country. Along with the expansion of palm oil across the nation causing deforestation of natural rain forest and conversion of peat land into plantation land there are several factors causing a tremendous increase in carbon dioxide (CO₂) emissions. Main causes of CO₂ emission apart from deforestation and peat-land conversion are the fires to create plantation land plus the fires burning waste products of the plantations itself. This paper describes a project that aims at the development of a remote sensing monitoring system to allow a continuous observation of oil palm plantation activities and expansion in order to be able to quantify CO₂ emissions. The research concentrates on developing a spaceborne synthetic aperture radar information extraction system for palm oil plantations in the Tropics. This will lead to objective figures that can be used internationally to create a policy implementation plan to sustainably reduce CO₂ emission in the future.

1. Background
In the past two decades the international community became aware of impacting factors that influence changes in our environment and the global climate. One of the identified global climate warming factors is the increasing green house gas (GHG) emission. Deforestation and forest degradation is one major contributing aspect to the global emission balance. Its share in total global anthropogenic CO₂ emissions accounts for 7 – 14% in the period of 2000 – 2005 [1].

Palm Oil became the most used vegetable oil in the world when it passed the consumption of soybean oil in 2004/2005 according to the United States Department of Agriculture [2]. This is no surprise due to the fact that it is the highest yielding crop with a rising demand based on increased income, population and biodiesel production. It takes only 1/10 of the size of the land needed for soybean to produce the same amount of yield [3].

With the increasing success of palm oil on the global market large areas of primary forest were converted into palm oil plantations. In 2012-2013 85% of the crude oil originates from Indonesia (52%) and Malaysia (34%) [4]. From Malaysia’s 32 million ha land area 19% (5.4 million ha) contain agricultural crops. Of these four million hectare were covered by oil palms in 2005 [5]. Malaysia is taking efforts to reduce deforestation of primary forest looking for alternatives to benefit from the popularity of palm oil, forming the second largest exported product of the nation. A large part of the

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increasing wealth of the population and the fast economic growth is based on the fossil fuel and palm oil industry. Many of the newly created oil palm plantations emerged by converting less beneficial crops, such as cacao, rubber and coconut into oil palms. Other efforts deal with the improvement of management practices to increase the yield from currently four tons per ha to a feasible ten tons per ha to reduce the area impact [3].

Apart from these issues the international agreement on Reducing Emissions from Deforestation and Forest Degradation (REDD+) under the United Nations Framework Convention on Climate Change initiated in 2005 provides compensation to tropical forest countries to protect forested areas and reduce CO₂ emission by deforestation. The successful implementation requires regularly updated spatio-temporal information on land use / land cover changes [6, 7]. Since monitoring entails continuous data acquisition it is not possible to rely on optical remote sensing (VIR) alone because especially in the Tropics persistent cloud coverage hinders cloud-free image acquisition. Examples show that it takes between one and seven years in average to get cloud-free scene [4]. A minimum of 12 months coverage contains the chance of one scene with less than 10% cloud cover [8]. Another issue in optical remote sensing is the degradation of the imagery through haze which is a very common phenomenon in Malaysia and other countries in South East Asia [9]. Synthetic aperture radar (SAR) sensors do not only provide complementary information to VIR images. The SAR is an active sensor that operates weather and daylight independent delivering information all year round at the time that it is needed. Clouds, haze and smoke do not prevent the sensor from providing images. The challenge in this respect is the different nature of radar data in terms of information content and interpretation. The intensity backscattered energy of microwaves is sensitive to texture, size and orientation of structural objects, moisture content and ground conditions. For the application discussed in this paper the interaction of microwaves with canopies, trees and soil is of interest. The longer wavelengths (e.g. L-band 15-20 cm) penetrate the canopy and deliver information on leaves, branches, stems and soil conditions; the longer the wavelength the greater the penetration [10]. It has been proven that radar is sensitive to the structure of the canopy. The received backscatter intensity represented in the image is a composition of interactions with the crown, the trunk and the ground surface. Using fully polarimetric SAR it is possible to derive a relationship between backscatter, texture and crop status [11]. If we consider an oil palm as crop this is very interesting. It would help to derive certain patterns for different growth stages of the oil palm. This is very relevant information for optimized and sustainable oil palm plantation management.

Using radar for land cover mapping is a recent technological development that has not been exploited in its full potential [7]. That is why a joint initiative between the Institute of Geospatial Science and Technology (INSTeG), UniversitiTeknologi Malaysia and SkyMap GlobalPtd. Ltd. aims at investigating the benefits of using radar satellite remote sensing to monitor palm oil plantations. The first step is to conduct a feasibility study to understand which parameters that are relevant to a sustainable palm oil plantation management can be derived from SAR data. For a proper, successful and sustainable oil palm plantation management it is necessary to monitor the plantation on a regular basis. From preparing the ground, through planting the trees, growing the trees plus their accompanying plants to prevent erosion etc., to nutrition and health status of the trees plus yield prediction there is a palm tree life long process to be managed. Therefore, the plantation owner needs regular and continuous access to a set of parameters that are vital to take decisions about fertilizer, pest control, soil moisture regulation, environmental impact, water quality, and yield.

The initiative builds on existing experience in connecting to efforts taken by the Federal Land Agency (FELDA) research centre for palm oil. An established cooperation with Felda Agricultural Services Sdn. Bhd. ensures exchange of information and access to oil palm plantations and laboratories to provide ground truth data for validation of developed procedures. The entire project is embedded in the UTM CO₂ Initiative using Palm Oil as application for the research focus. The project headed by Sune Hansen, Director of the Palm Oil Research Centre of UTM focuses on CO₂ in the
palm oil industry within four major components: The Science of CO₂, Technologies and Methods, Regulatory & Policies and Training & Capacity Building.

The following sections of this paper will describe achieved results using spaceborne SAR for forest monitoring in general (Section 2) and oil palm plantations in particular (Section 3). Then Section 4 elaborates on the research methodology, identified data sources and planned processing flow. At the end the conclusions and outlook are summarized in Section 5.

2. SAR for forest monitoring

The use of radar remote sensing for forestry applications in the Tropics started with sensors on-board of aircrafts. In 1993 the usefulness of fully polarimetric airborne SAR to derive relationships between backscatter and tropical forest structures was investigated [12]. The research team was able to quantify an empirical relationship between biomass, forest structure and backscatter properties. Another study conducted by [13] showed the feasibility of using high resolution radar at a scale of 1:50,000 for the monitoring of a sustainable forest management for timber production in 1997. In parallel researchers started to exploit spaceborne SAR with the launch of the European Remote Sensing Satellite-1 (ERS-1) making SAR images more widely available for forestry applications. Today we have access to three different wavelengths, increased resolution and multiple polarizations which increases the information that can be derived to describe the status and useful parameters of the forest. The wavelength determines the depth of penetration into the canopy. The polarization is sensitive to different orientations of the tree and forest structures (stems, branches, twigs, leaves or needles) [14].

2.1. Spaceborne SAR sensors for forestry

From the literature commonly used radar satellite sensors during the past six years are

- European Remote Sensing (ERS-1/2) satellites: [14-16]
- Japanese Earth Resources Satellite (JERS-1): [14, 16-18]
- Canadian Remote Sensing Satellite Radarsat-2: [19-23]
- Advanced Land-Observing Satellite Phased Array L-band Synthetic Aperture Radar (ALOS PALSAR) (only 2013): [6, 24-26]
- High-resolution radar satellites TerraSAR-X/TanDEM-X: [10, 27-30]
- Environmental Satellite (Envisat) Advanced Synthetic Aperture Radar (ASAR): [26, 31-33]

The Kyoto & Carbon (K&C) Initiative by the Japan Aerospace Exploration Agency (JAXA) Earth Observation Research and Applications Centre (EORC) in 2000, to support environmental conventions, carbon cycle science and natural conservation, produced during the years a lot of useful results using ALOS PALSAR (L-band) in forestry. Lessons learned from all the research that has gone into this data have led to tremendous advancement in knowledge for information extraction from SAR in forestry applications. With the increase in available high-resolution multipolarization satellite SAR sensors the possibilities in up-to-date mapping of forest related parameters has become more and more feasible.

2.2. Change detection

The most straightforward application of SAR in forestry is the identification of changes, in particular the mapping of deforestation or clear-cuts. Recent findings underline the possibility of using L-band radar to detect losses and gains in above-ground biomass woodland [34]. Also C-band radar has proven its suitability to continuously detect large-scale, clear-cut and selective logging in a tropical rainforest irrespective of weather conditions [35]. [36] used multi-sensor C-band SAR to map forest changes over large areas in China in a ten year period with great success. They applied interferometric and classification methods to derive the thematic maps. X-band radar has been used for storm damage detection fusing multi-aspect SAR images [37]. The authors point out the advantage of increasing
2.3. Biomass estimation

Backscatter from SAR is correlated to stem volume which means that biomass estimates can be derived. Again the information quality increases with wavelength since shorter wavelengths interact strongly with the canopy of the trees. For stem volume estimates L-band (3.75 – 7.5 cm wavelength) or P-band (> 1 m wavelength) are suitable [38]. P-band so far is only available on airborne platforms.

Other researchers succeeded with Radarsat-2 C-band SAR because they applied advanced processing techniques to estimate biomass making use of polarization, incidence angle, high spatial resolution and texture, especially from ratio images [39].

[10] presented a method for biomass estimation using SAR and derived parameters. They perform the process in two steps:

1. Analysis of selected Haralick textural parameters (HTP), i.e. entropy, contract, correlation, energy and homogeneity
2. Variogram analysis

In a case study they identified forest in VV (vertical transmitted, vertical received) polarized TerraSAR-X data (X-band, wavelength 3cm) of 0.5m ground sampling distance (GSD). Applying the support vector machine (SVM) supervised classifier to the image plus the derived texture parameters they were able to improve the classification accuracy by more than 50%.

A sub-parameter in biomass estimation is the derivation of tree heights that can be performed using polarimetric interferometric radar. The idea behind this concept is applying the knowledge that an HH microwave signal has a double bounce from the ground and the tree canopy. HV polarized signals have a smaller penetration into the canopy but a large diffuse scattering. VV backscatters most from the canopy and less from the tree trunk [40].

3. Oil palm plantation monitoring with SAR

Having understood the scientific achievements in using active microwave remote sensing for forestry, it takes a short step to convert the findings to applications in tree plantations and for oil palms in particular. In a way the applications for oil palm plantations is somewhat more straight forward since we already know what we are looking at. The trees are planted systematically. The plantation is covered with one species only. Each plantation by itself contains trees of the same age. The practices and activities to grow oil palms, to nurture and to harvest are specified. There is very little variation.

Similarly to applications in forestry in general, researchers have used SAR to estimate above-ground biomass (AGB) of oil palms. Using the backscatter coefficient of fully polarized ALOS PALSAR data [41] produced biomass estimates for an oil palm plantation in the state of Perak, Malaysia. Best results were obtained from VH polarization data using a window size of 5x5 for the Laplace filter to detect large changes in pixel values. Another study used a regression analysis of HV-polarized PALSAR data to estimate biomass of oil palm plantations in Sabah (Borneo), Malaysia. The authors found a precipitation significant effect on the backscatter. Also scattering from large leaves of mature palm trees significantly changed the estimates [42]. This definitely needs more investigation.

The measurement of changes in oil palm plantation expansion does not seem to be a major problem using multimodal SAR imagery [16].

However, the establishment of a correct relationships between backscatter and reality parameters of oil palm trees needs to consider multimodal data, ranging from multitemporal acquisitions, through multimodal SAR images, up to verification data from optical imagery or fieldwork [43].
final test site which is most probably going to be a ‘super’ test site near the Malaysia National Park Taman Negara in the area of Jengka, Malaysia we will start the remote sensing data collection. The test data package will consist of COSMO-SkyMed SAR, ALOS PALSAR, TerraSAR-X, IKONOS, WorldView-2, and other available scenes.

Regarding the optical data the selection will depend on existing data from the archive with < 10% cloud coverage. The radar images will be taken at different times in coordination with ground truth data collection at the test site.

The data will be pre-processed to correct for atmospheric effects (optical), sensor-induced errors, speckle reduction (SAR) and geometry. All images will be geocoded to create a joint reference which enables multimodal image processing and mapping. The optical data and the ground truth will be taken as reference data to derive oil palm plantation relevant parameters from the SAR data.

The following SAR image processing techniques, for oil palm plantation parameter extraction are taken into account:

- multifrequency approach and use of polarimetric information for oil palm tree age determination using normalized backscatter coefficients and segmentation [44]
- classification of polarimetric and interferometric data to estimate forest heights (biomass); comparison to biomass from empirical BioMass Index (BMI) [28, 45]
- extraction of biomass from HV polarized L-band SAR through adapted Malaysian above ground biomass index of oil palm plantation [41]
- oil palm plantation analysis using the Bayesian approach based on mixture modelling followed by Markov Random Field (MRF) classification [7]

Of special interest will be the investigation of the potential of high-resolution multifrequency, interferometric and polarimetric SAR to provide information on oil palm frond shapes and changes as well as moisture parameters of plants and soil. The establishment of oil palm plantation parameter extraction models will be supported by optical image exploitation. For the multimodal image processing various analysis methods will be investigated amongst which joint classification of stacked multimodal images as well as fused remote sensing images are two options. Further image enhancements prior to analysis will be considered. Of high interest is the recent trend in integrating Light Detection and Ranging (LiDAR) and hyperspectral data for forest analysis [46].

5. Conclusions and Outlook

From the literature it becomes obvious that a stand-alone SAR system will not provide the necessary information needed for sustainable oil palm plantation management. The system has to be seen in the context of multimodal imaging. While the radar signal is mainly sensitive related to the woody biomass optical imagery delivers information in respect to seasonally variable plant leaves. However once a relationship between SAR and optical remote sensing data in terms of parameter extraction has been established, it is anticipated that an operation SAR image acquisition for the timely information extraction is sufficient to draw conclusions. Another important advantage is the integration of different radar sensors. With the availability of various operational high resolution fully polarized systems, such as Constellation of small Satellites for the Mediterranean basin Observation (COSMO-SkyMed), Environmental Satellite Advanced Synthetic Aperture Radar (ENVISAT ASAR), Advanced Land Observing Satellite Phased Array type L-band Synthetic Aperture Radar (ALOS PALSAR), TerraSAR-X, its twin-satellite TanDEM-X, add-on for Digital Elevation Measurements and upcoming systems like Sentinel-1 additional, valuable and regularly accessible information can be derived to the benefit of sustainable palm oil production. It should be mentioned that the trend in forest monitoring is to use LiDAR data in combination with polarimetric SAR and optical data. In this context hyperspectral imaging plays an important role. With the upcoming hyperspectral German satellite sensor onboard of the Environmental Mapping and Analysis Programme (EnMap) it is hoped to have
access to additional valuable information. The satellite has been re-scheduled to be launched in 2017. It cannot be neglected that a multimodal approach always leads to improved, more reliable and trustworthy results.

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