Interferometric processing of C-band SAR data for the improvement of stand age estimation in rubber plantation

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ABSTRACT

Rubber ranks the second largest plantation in Indonesia after oil palm. While oil palm plantations have been exploited mainly by large companies, many rubber plantations are still managed by peasant farmers who maintain its biodiversity. Due to its broad and scattered location, monitoring tropical rubber plantation is a crucial application of active remote sensing. In this paper, the backscatter coefficient of Envisat Advanced Synthetic Aperture Radar (ASAR) is compared to interferometric coherence to study the relationship between stand age and SAR parameters. It is shown that VV polarized C-band SAR achieves its saturation level in plantations aged about 5-10 years. Extension of saturation level can be achieved by processing an interferometric pair of ASAR data, which results in interferometric coherence. In this paper, coherence can take up to 20 years stand age to achieve prior to saturation. Since stand age is highly related to biomass, this finding argues that the biomass can be best estimated using coherence.

Keywords: backscatter, coherence, rubber, saturation, stand age

1. INTRODUCTION

Unplanned forest utilization, backed by weak law enforcement, generates tremendous deforestation in major islands of Indonesia. Despite monitoring schemes having been developed and implemented, tropical forest in Indonesia tends to decline for multiple reasons. In many remote areas, shifting cultivation is responsible for the deforestation or degradation1, especially given a short fallow period2. However, scientists argue that this kind of conventional agriculture system has strong impact on overall environmental degradation3. Instead, development of plantations in the past that were fairly uncontrolled has been disputed as having a significant impact.

In Indonesia, the majority of forest conversions lead to oil palm, timber or rubber plantations. The Indonesian Statistical Agency recorded that more than 5 million hectares of oil palms were established in 2010. This commodity has been a major concern to researchers4,5, in part due its rapid expansion. Oil palm plantations have been established and managed by multiple stakeholders, including private and state-owned enterprises as well as local farmers. Pulp and paper industries have attracted research as well6. The industries have developed vast timber plantations, especially comprising Acacia mangium (on mineral soils) and Acacia crassicarpa (on peat soils), in the Eastern provinces of Sumatra. Similar to oil palm industries, pulp and paper industries were also criticized for making use of timber sourced from natural forest. Despite its high coverage, rubber plantation seems to create least conflict in many regions. This could be due to the fact that rubber plantations were developed to a limited extent by private companies. The developers of rubber plantations in Indonesia have been local farmers who have practiced environmentally-sound land use for centuries.

Monitoring those plantations is an overwhelming task because of their remoteness and scattered locations. For these reasons, remotely-sensed imageries, especially those captured by sensors on space platforms, offer a sensible, cost-effective and timely approach. Historically, multispectral imagers such as Landsat and SPOT have been exploited. Many scientific reports have been dedicated to the observation of plantations within the context of land use studies4. Analyses of rubber plantations have also been conducted, for instance using MODIS7 or Landsat data8. Nonetheless, the nature of the tropical region inhibits their full capability to assist in the monitoring of plantations. Efforts have been made to minimize clouds or other atmospheric disturbances, including the exploitation of multi-temporal information fusion, however, the problem persists in some Indonesian regions.

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Synthetic Aperture Radar (SAR) offers another scheme to acquire the information. It provides day or night observation capability in almost all weather conditions. To some extent, monitoring rubber plantations has been conducted using various SAR data. The majority of studies have utilized backscatter information retrieved from various satellite-borne SAR sensors. Nonetheless, very limited information, if any, provides clear evidence on variations of backscatter coefficients related to stand age, and information on age can be used as a proxy to biomass contained at a site.

This paper exploits C-band Envisat ASAR data to study their utility in rubber monitoring. In general, the aim of this study is to assess the relationship between plantation stand age and SAR backscatter as well as complex coherence derived from Interferometric SAR pairs.

2. METHODOLOGY

2.1 Study site and dataset

The research was located in Subang Regency, West Java. The rubber monoculture plantation is managed by PT. Perkebunan Nusantara VIII, a state-owned company that also manages similar plantations in other regencies in the province as well as in nearby Banten Province (Figure 1).

![Figure 1. Research location in lowland area of Subang. Light grey denotes regency boundaries.](image)

In this research, all SAR datasets were obtained from the European Space Agency (ESA) under the C1P.11309 project. The SAR data consist of two pairs (dated 21-09-2008 and 26-10-2008) of VV polarized Envisat ASAR collected on Single Look Complex (SLC) mode, enabling Interferometric (InSAR) processing. The perpendicular baseline of the pair is 10 m.

2.2 Analysis

The two SLC ASAR data sets were converted to backscatter coefficients using the Rosich-Meadows equation shown below.

\[
\sigma^0 = \frac{DN^2}{K} \left( \frac{R}{R_{ref}} \right)^3 G(\theta) \sin(\alpha)
\]

where \( DN = \sqrt{I^2 + Q^2} \)

Notation K = calibration constant; DN = digital number; G(\theta) = two-way antenna gain at look angle; R = slant range distance; \( R_{ref} \) = reference slant range distance; \( \alpha \) = incidence angle.

The data were then filtered using Gamma MAP with a 5x5 kernel size, prior to terrain correction. In this research, Range-Doppler terrain correction was implemented, delivering an output image with 25 m ground spatial distance. Both data sets were then time-averaged to produce a single backscatter coefficient image for further analysis.
In addition to the backscatter coefficient, as described above, this study also employed interferometric coherence derived from an interferometric pair of SAR data. Interferometric coherence measures stability of the backscattered SAR signal. The coherence also represents normalized cross-correlation of complex signals. Coherence can be defined as:

\[ \gamma = \frac{E[v_1 \cdot v_2]}{\sqrt{E[v_1^* \cdot v_1] E[v_2^* \cdot v_2]}} \]  

(2)

Notation \( E \) represents ensemble averaging. Coherence (\( \gamma \)) spans from 0 (total decorrelation) to 1 (strong backscatter). The loss of coherence indicates changes on the ground. Decorrelation of coherence data is affected by various conditions. Temporal decorrelation has been reported as the most prominent factor in a repeat-pass configuration, where properties of an object during the course of satellite revisit are significantly changed. Land cover change is mostly the cause of temporal decorrelation. In addition, alteration of satellite geometry, known as spatial decorrelation, also merits a special mention. In the case of hilly or mountainous terrain, one should also consider topography as an important source of decorrelation, especially when taking observations in two or more directions, for instance ascending and descending orbits. In very rare cases, atmospheric effects can be a source of decorrelation, especially when X- or C-band is applied.

Backscatter coefficients as well as coherence data were compared with stand age data collected during field campaigns in 2010 and 2013. Two most useful models are discussed in this paper, i.e. polynomial and saturation. The polynomial model was employed by Rosenqvist9 to analyze the relationship between backscatter coefficients and rubber biomass and tree height. Results of the research, however, indicate that SAR signals achieve their saturation at a particular level that depends on the frequency used.

3. RESULTS AND DISCUSSION

3.1 Dependency of backscatter coefficient to stand age

Backscatter coefficients at all possible polarization configurations have been the most useful dataset. In this paper, however, only VV polarization is discussed. This kind of polarization has been adopted by ERS-1, ESR-2 as well as Envisat ASAR, which in turn provides long term records of radar observation on Earth.

Derivation of radar backscatter coefficients from SLC data plotted against age of rubber stands is presented in Figure 2. Associated statistical attributes of tested models are shown in Table 1.

![Figure 2. Curve fitting on backscatter coefficients. Polynomial and saturation models are shown by solid and dashed lines, respectively.](image_url)
Previous research\textsuperscript{9} found that VV-polarized C-band SAR was unable to distinguish clear-cut forest to all biomass levels of rubber plantation in Malaysia. Since the biomass is highly correlated with stand age, one can infer that mapping stand age in rubber plantation using the SAR system is difficult. This research, on the contrary, shows that identifying stand age is possible especially for young plantation trees. Despite the existence of high level variation at certain ages, a curve fitting procedure can reveal a relationship pattern in up to 5-year old rubber trees. Calibration of SAR imagery is probably the main cause of the difference between this research and the result of Rosenqvist\textsuperscript{9}, since rubber plantations used by both projects were located in similar climatic regions and situated in fairly flat terrain.

This research also shows that the difference of $\sigma_0$ between barren (or recently planted trees) and the saturation level is about 1 dB. This level is considered to be a very low dynamic range compared to 5 dB in L-band as modeled by Karam et al.\textsuperscript{12}. Low dynamic range creates difficulty in separating objects with similar patterns. However, this is often understood in the case of C-band SAR since it has limited sub-canopy penetration. The main backscatter contribution is due to canopy, while scattering of sub-canopy layers such as stem, twigs and sub-stratum canopy is negligible.

Both R-square and RMSE values indicate that the polynomial model outperforms the saturation model. However, despite producing the highest coefficient of determination, the polynomial model cannot provide a sensible description on how the model should be interpreted. The declining trend after a certain stand age (nominally 10-15 years) has no further explanation. The saturation model, on the other hand, provides a better explanation of how the wave interacts with rubber stands.

### 3.2 Assessment of coherence data

Table 2 presents statistical relationships of the models between stand age and the coherence dataset. It suggests that the polynomial model performs better than the saturation model, similar to previous results using the backscatter coefficient. However, the $R^2$ difference applied to coherence data is very low in comparison to the backscatter coefficient. There is no significant improvement in distinguishing stand ages using backscatter coefficients and coherence using the polynomial model, while the saturation model clearly improves using coherence.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Polynomial</th>
<th>Saturation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a$</td>
<td>0.0003</td>
<td>0.1862</td>
</tr>
<tr>
<td>$b$</td>
<td>-0.0144</td>
<td>0.0862</td>
</tr>
<tr>
<td>$c$</td>
<td>0.3931</td>
<td>0.2079</td>
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<tr>
<td>R-square</td>
<td>0.3016</td>
<td>0.3009</td>
</tr>
<tr>
<td>RMSE</td>
<td>0.0934</td>
<td>0.0934</td>
</tr>
</tbody>
</table>

The saturation model is presented in Figure 3. It indicates that the saturation level of coherence data reaches 15-20 years, far beyond the saturation level achieved by the backscatter coefficient. The result is fairly similar to previous research\textsuperscript{13}, which reported that tandem ERS signals lost their capability to classify sitka spruce forest in the UK at an age of about 20 years.
Figure 3 clearly shows some outliers whose source remains unknown. However, outliers can occur if atmospheric disturbance exists as demonstrated by Rocca et al.14. Meteorological short-term variation such as temperature has also been reported to be significant to temperate forest15. As the time of SAR acquisition was approximately the end of the dry season, soil moisture may have caused variation in coherence data.

4. CONCLUSION

Despite its decadal establishment, radar remote sensing of tropical rubber plantation is fairly incomplete. This research has analyzed the backscatter coefficient, which is conventionally used for monitoring vegetation cover, in comparison with coherence data after interferometric SAR processing. Similar to previous findings, this research found that the VV polarized C-band SAR backscatter coefficient is quickly saturated in 15-20 year old rubber trees. Both polynomial and saturation models used in this experiment cannot accommodate variations in stand age. By implementing interferometric SAR techniques, a stronger relationship can be developed between stand age and the coherence dataset. This research concludes that saturation of SAR data on older rubber stands can be extended by incorporating coherence. Removing outliers may not affect the general trend of the model, however, it significantly improves accuracy.

5. ACKNOWLEDGMENTS

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REFERENCES


