Leaf Area Index and Biomass Assessment over Tropical Peatland Forest Ecosystem using ALOS Palsar and ENVISAT ASAR data

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Abstract

Provision of accurate forest parameter properties is important as a basis for forest resources monitoring and carbon cycle assessment. The present study aims to model leaf area index (LAI), above ground biomass and carbon stocks over tropical peatland forests using single polarization SAR, full polarimetry SAR (PolSAR) data. Single band ALOS Palsar data (HH band, acquired on November 17, 2008) and polarimetric data (HH, VV, HV and VH, collected on April 4 and May 5, 2007) are used for the study. A series of ENVISAT ASAR data (5 datasets) collected in 2004 – 2005 are also used to model the forest properties. Landsat ETM data collected on January 22, 2009 is also used as a reference. The relationship between forest parameters and normalized radar backscattering is estimated using empirical models, and preliminary results show that Polarimetric SAR data has better correlations with the LAI and biomass than single polarimetry SAR data. The field data were collected during field work in March – April 2009 and the reliability of identified forest classes was also assessed from available Landsat ETM data. Analysis will be conducted on the basis of statistical correlations between radar data and modeled forest properties, such as LAI, biomass and tree age. This study focuses on a unique tropical peatland ecosystem in Kampar Peninsula, Sumatera, Indonesia, which has great potentials as carbon sinks and/or sources. Only few studies have been conducted in the study area due to limited satellite and field observation data.

Keywords: ASAR, ALOS Palsar, peatland forest, biomass, LAI

1 Introduction

Peatlands are the result of a fine balance between hydrology, ecology and landscape morphology and consist of dead, incompletely decomposed plant material that has accumulated over thousands of years in waterlogged environments that lack of oxygen (Jaenicke et al., 2008; Page et al., 1999), and a change in one of these three components will lead to a change in the others and inevitably peat accumulation rate (Page et al., 1999). Due to its characteristics, peatlands have an important role as carbon sink that stores huge amounts of carbon. Within the context of global climate change, there has been an increased interest in tropical peatlands because of their importance as carbon stores and their role in carbon fluxes (Jaenicke et al., 2008; Page et al., 2002; Rieley and Page, 2005). Compared to other terrestrial ecosystems, peatlands are the most efficient carbon sink sources (Hooijer, 2005; Wosten et al., 2006). Although peatlands cover only 3% of the Earth’s land surface, they contain as much carbon...
as all terrestrial biomass, twice as much as all global forest biomass, and about the same that can be found in the atmosphere. Peatlands store carbon for thousands of years and play critical role in biodiversity conservation and hydrological regulation (van Beukering et al., 2008).

Remote sensing is an alternative approach which is useful to map tropical environments at local and/or regional scale (Wijaya et al., 2010a). With the successful launching of recent satellites, vegetation monitoring in forested landscape becomes more effective and offer a great possibility for information updating on a regular basis. Although applications and methods development employing remote sensing for mapping of forest stands and forest properties modeling over tropical forest landscapes have been well established (Foody et al., 2003; Hajnsek et al., 2005; Houghton, 2005; Lefsky et al., 2002; Lu and Batistella, 2005; Lu, 2006; Rahman et al., 2005; Steininger, 2000), the knowledge of this approach for tropical wetlands is relatively poor (Wijaya et al., 2010b).

Applications of microwave remote sensing for biomass estimation allow the provision of additional information measured from the ground objects, since they are insensitive to the cloud-free daylight conditions for image acquisition. The application of SAR data for mapping of tropical forest properties has been widely applied (Fransson and Israelsson, 1999; Hajnsek et al., 2005; Isola and Cloude, 2001; Kuplich et al., 2005; Luckman et al., 1996), but few studies found applying this data in tropical wetlands. Besides, empirical models of microwave instrument data are known to be very sensitive to the density, shape, length, dielectric properties, and orientation of the scatterers (Kingsley and Quegan, 1992). The X-band (2.4 – 3.75 cm) SAR data is useful for terrain mapping and for discriminating the top canopy of vegetated lands. Some studies showed that the utility of single polarization C-band data (3.75 – 7.5 cm) may bring some limitations for distinguishing biomass in regenerating forests and deforested areas, because the radar backscatter becomes insensitive especially if the soil is dry and the influence of water is minimized (Saatchi et al., 1997). In contrast, L-band SAR data (15 – 30 cm) showed good ability for modeling the forest parameters under dense vegetation (Luckman et al., 1997; Rauste, 2005). The capability of L-band radar backscatter to penetrate through the forest canopy makes this data is useful for mapping the forest structure, including for above ground biomass (AGB) estimation (Luckman et al., 1997). Recent studies confirmed that the empirical AGB models generated from the L-band radar backscatter provide favorable estimation results, especially if the data has dual-polarization configuration. Using dual polarimetry SAR data the backscatter signal is more sensitive to forest biomass and forest structure because of tree trunk scattering, thus showing better discriminations of different forest successional stages (Ranson et al., 1997; Rignot et al., 1997; Saatchi et al., 1997).

Similar to vegetation indices generated from optical RS data, the biomass estimation from radar backscattering is also limited up to a certain biomass level due to saturation problems. The backscatter saturation limits are dependent on the geometry of data acquisition, the polarization compositions, the wavelength, and the complexity of vegetation structure. These values may vary from 20 – 40 Mg/ha at C-band to close to 100 Mg/ha at L-band (Imhoff, 1995). However, in very dense tropical rain forests it is common to find biomass over 300 Mg/ha, which is far beyond the suggested saturation limit.

2 Study Area
This study specifically considers the peatland forests in Kampar Peninsula, Riau Province, Sumatera, which is geographically located between 101°50’ E and 104°07’ E and between 0°10’ dan 1°14’ N (Figure 1) The Kampar Peninsula is a wetland forest consists of great numbers of natural resources. The area has a size of approximately 700,000 ha, and peatlands in this region are mostly covered with 2-layer forest canopies. Peatlands in this region have depth from 50 cm (very shallow) to more than 20 meter (very deep). The peatland forests in Kampar Peninsula cover 17% of total peatlands in Riau Province (4.044 million ha), and for the entire country this province covers 56% of total 20.5 million ha of peatlands in Indonesia (Wahyunto et al., 2005).
Thus, the peatlands in Kampar Peninsula play an important role to maintain the stability of tropical peat swamp forests in Indonesia and SE Asia region. Similar to lowland peat swamp forests in Central Kalimantan, the peatlands in Kampar Peninsula are also heavily degraded, deforested and drained, mainly for oil palm and pulp wood plantations. The activities of Asia Pacific Resources International (APRIL) company, a giant private pulp mill factory in Asia, have worsened the degradation of peatland forests over this region as the opening of new pulp wood plantations often compensate the sustainability of peatland forests. Additionally, increasing illegal logging activities by local farmers is also a major problem, particularly after the implementation of decentralization policy in 1999 (Dermawan et al., 2006).

Field data was sampled over the study area in 2009 during dry season collecting 83 sample plots. In each sampling plot standard tree parameters (i.e. diameter-at-breast height (dbh), commercial tree height, total tree height, number of stems) were measured and tree species information were also recorded. Leaf area index (LAI) was measured using hemispherical camera, and converted into LAI value following standard calculation procedure. In each sampling plot, peat thickness was measured and the soils were sampled to study the concentration of peat and mineral soils. This data are important to calculate total carbon in the peat soils.

3 Results and Discussion

Field Data Descriptions

Collected sampling plots data show marked difference of tree canopy height from the early age plantation forest class (PF1) to mature plantation forest (PF3). However, natural peat swamp forest (PSF) shows considerably shorter canopy height than the old plantation forest (PF3) (Figure not shown here). Similarly, tree diameter (dbh) in PSF class is smaller than that in PF3 class. The lower functional stand characteristics in PSF are probably due to the dominance of tall but slim various palm tree species in peat swamp forest, which are highly variable depending on the successional stage of this particular forest class.
Also, Acacia mangium *sp.* that dominates the plantation forest classes can grow very rapidly even in very poor soils (e.g. low pH soils). Variations of peat depth in sampled forest classes, however, show no significant differences, but PF2 sampling plots have relatively deeper peat soil as compared to other classes. It means that the peatlands conversion into plantation forests or other landuse does not consider the peatlands sustainability, and in the long term this may certainly trigger carbon sequestration and severely effect hydrological functions of the peatland forests.

Figure 2 Stand volume, above ground biomass, carbon stocks and LAI of sampling plots data

Table 1. Pearson correlations of SAR data and forest biophysical properties

<table>
<thead>
<tr>
<th></th>
<th>Biomass (ton/ha)</th>
<th>LAI</th>
<th>Age (year)</th>
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<tbody>
<tr>
<td>FBS_HH</td>
<td>0.49</td>
<td>0.05</td>
<td>0.16</td>
</tr>
<tr>
<td>P_LR_HH_7001</td>
<td>-0.51</td>
<td>0.04</td>
<td>0.01</td>
</tr>
<tr>
<td>P_LR_HV_7001</td>
<td>0.41</td>
<td>0.11</td>
<td>0.51</td>
</tr>
<tr>
<td>P_LR_VH_7001</td>
<td>0.39</td>
<td>0.14</td>
<td>0.47</td>
</tr>
<tr>
<td>P_LR_VV_7001</td>
<td>-0.06</td>
<td>0.83</td>
<td>0.15</td>
</tr>
<tr>
<td>P_LR_HH_3001</td>
<td>-0.32</td>
<td>0.23</td>
<td>-0.15</td>
</tr>
<tr>
<td>P_LR_HV_3001</td>
<td>0.27</td>
<td>0.31</td>
<td>0.55</td>
</tr>
<tr>
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<td>0.46</td>
</tr>
<tr>
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<td>0.40</td>
<td>-0.39</td>
</tr>
<tr>
<td>ASAR_6760</td>
<td>0.41</td>
<td>0.12</td>
<td>0.46</td>
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<tr>
<td>ASAR_6759</td>
<td>-0.39</td>
<td>0.14</td>
<td>-0.36</td>
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<td>ASAR_6758</td>
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<td>0.97</td>
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<td>ASAR_6590</td>
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<tr>
<td>ASAR_6588</td>
<td>-0.39</td>
<td>0.13</td>
<td>-0.39</td>
</tr>
</tbody>
</table>

The volume of standing stocks was calculated using available allometric equations for acacia plantation forests and peat swamp forest (Figure 2) applying biomass conversion models proposed by Brown (1997), the above ground biomass was estimated. Carbon stocks over the forests were predicted, assuming 50% of the biomass contents are carbon (Brown et al., 1989). We found the stand volume, biomass, and carbon were significantly increased from following the successional forest stages from the least complex to the most complex vegetation structure (i.e. from PF1 to PSF). These information explain that under normal conditions, natural peat swamp forests has contained higher biomass, thus higher carbon, than the plantation forests, and the conversion of the peatland forests will release huge amounts of carbon into the atmosphere that contributes to global warming and climate change over the South East Asia Peninsula.

Correlations of SAR data and Forest Biophysical Properties

Table 1 shows that biomass significantly correlates with HH band of Polarimetry Palsar (PLR) data. Similarly, LAI has higher correlations with HV band of PLR data and ASAR data. These SAR data were acquired in February, April and May during the end of rainy season. Surprisingly, tree age has significant
correlations with HV and VH bands of PLR data. This high correlation may be contributed from the plantation acacia forest that has regularity in its succession and stand structure.

Figure 3 Biomass model from PLR HH band data

Figure 4 LAI models using Palsar PLR data and ASAR data

We developed a simple model for above ground biomass using ALOS Palsar HH band PLR data \( (r = -0.51) \), and found the linear regression model explains 22% of biomass variance (Figure 3). This might be due to high variations of biomass on the test site, and the limitation of SAR data to penetrate through forest canopy. Further SAR filtering processes and the use of mean value from several neighboring pixels instead of single pixel value in the modeling should be considered.

Figure 4 shows that an exponential model of Polarimetry ALOS Palsar data (adjusted \( r^2 = 0.53 \)) is more accurate than the polynomial model of ASAR data (adjusted \( r^2 = 0.27 \)) to explain leaf area index (LAI) variance. However, the HV band of PLR data is not sensitive to estimate higher LAI (LAI > 3). It would be due to the model limitation, or the structure of tree leaves in peatland ecosystem that is very humid and compensates the SAR data to model this parameter.

Figure 5 Tree age models from HV and VH bands of ALOS Palsar PLR data

Along with the sampled secondary forest, we also collected sample points of plantation acacia forest. The correlations show that HV \( (r = 0.86) \) and VH \( (r = 0.85) \) band of Palsar PLR data provide higher correlations with this parameter. The linear models of both data have confirmed these correlations. Both models has coefficient determination of more than 0.60, given acceptable error estimate.

Further study has to be conducted in order to improve the modeling of stand parameters over tropical peatland environments, which are very humid, high variations in terms of tree phenology, and coupled with the disturbance from atmospheric attenuations.

4 Conclusion

Modeling of tree parameters over tropical peatland regions is relatively new for remote sensing application. This study observed different SAR data, using single and full polarimetry SAR for modeling
the biomass, LAI and tree age in this particular ecosystem. We found that correlations between ALOS Palsar PLR data is relatively higher than single polarimetry Palsar data and ASAR images, to model such forest properties. However, the modeling of biomass, LAI and tree age using SAR data is another challenging task. The fitting process, selection of appropriate algorithm (i.e. linear or polynomial) should be taken carefully. Further study should be carried out to improve the accuracy of the model considering different SAR properties, and to include InSAR and PolinSAR parameters in the model.

References


