Identification of Tropical Peatland Using ALOS 2 Palsar

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Abstract. In Indonesia, a huge amount of peat has accumulated under peat swamp forest over millennia. However, a repeatable large-scale fire as a result of land clearing has rapidly devastated these tropical peatlands. These disturbances (e.g. climate change, deforestation, peatland drainage, forest and peatland fires, and land conversion) change the ecosystem respiration and resulting a high carbon emitted to the atmosphere. To restore the peatland ecosystem, Indonesia government makes a special force by using three activities, namely rewetting, replantation, and communal empowerment. These activities need an accurate peatland monitoring. However, accessing the spatial variation of the peatland is quite limited, difficult and laborious. Therefore, we investigated the existence of tropical peatland in Siak, Riau Province, Indonesia. We measured soil moisture at four different types of land cover (namely; forest, oil palm, shrubs, and agriculture) a long with two types of peat conditions. We estimated the Constanta Dielectric ($\varepsilon$) values obtained from a fully polarimetry for ALOS 2/PALSAR. Results indicated that the $\varepsilon$ of oil palm was lower in non-peat area than in peat area, whereas the decrease in $\varepsilon$ probably in peat area resulted from the rapid growth of oil palm.

Keywords: Polarimetric SAR, Constanta Dielectric, Soil Moisture, Land Cover Types, Peat

1. Introduction

Peat is soil comprised of partly decayed plant material formed in wetlands. The peatlands are habitats with a highly specialized flora and fauna. The peatlands also play an important role in global climate regulation. It covers cover only 3% of the land, but contain more carbon than the entire forest biomass of the world. The peatland located in tropic area, is widely distributed over $7 \times 10^5$ km$^2$ (about 5.21 % of the total global peatland area). It is mainly located in Indonesia and stores soil carbon up to 57.4 Pg., which accounts for ~ 12% of the total global peatland area [11]. However, these tropical peatland have been rapidly devastated by logging, poor land management practices, such as extensive plantation development, and enormous drainage in the last decades [9]. These activities drained the peatland, and well-preserved carbons were released as greenhouse gas to the atmosphere. The peatlands have also experienced repeatable large-scale fires as a result of land clearing [10], and lowered groundwater level (GWL) in the late dry season, especially when strong El Niño drought arise [7]. The fires alters peat soil properties, reduces plant cover, plant composition; whereas severe drought can increase tree mortality, and brench huge amount of carbon into the atmosphere. It also
produces long lasting smoky underground blazes that impact widespread public health. These conditions along with associated environmental and phenological characteristic give different impact on ecosystem respirations, and ultimately change the flux of carbon to the atmosphere. To restore the peatland ecosystem, Indonesia government makes limitation on the extent of plantation development in order to minimize the rate of this peat loss [13]. The government also makes a special force by using three activities, namely rewetting, replantation, and communal empowerment [14;15].

Land monitoring have been widely conducted using surface reflectance, which are derived from satellite data. This information is important for stakeholders and governments, as they are able to detect trends, seasonally and anomalies from a frequent and large-scale observations. However, monitoring and mapping tropical peatland is quite limited. The lack of this information is due to high attributes of cloud and aerosol influences the usability of satellite images. On the other hand, Synthetic Aperture Radar (SAR) with the use of multi-polarized L-band airborne images is highly suitable for detecting coastal wetlands [20]. They indicated that the HV polarization was the best for mapping abrupt boundaries in the coastal zone, the VV was the best for recognizing intertidal area morphology under low spring tide conditions, and the HH was the best for mapping coastal environments covered with forest and scrub vegetation such as mangrove and vegetated dunes. The radar system with a low incidence angle of the beam was also suitable for estimating information on soil moisture [3].

In this paper, radar scattering mechanisms for peatlands are examined in order to determine the existence of tropical peatland. It is known that peat and volumetric water content of a soil are closely related, and the possibility of a peat loss occurring becomes high when the volumetric water content of a soil is low. Thus, we evaluated soil moisture from the field, and estimated its spatial variation from the Advanced Land Observation Satellite (ALOS 2) Phased Array type L-band Synthetic Aperture Radar (PALSAR).

2. Material and Methods
2.1. Site Descriptions
The study sites (1.275 °N, 100.906 °E – 0.347 °N, 102.183 °E) are located at two different conditions of peat in Siak, Riau Province (Figure 1, Table 1). The study area has a total area of 8275 km² and is in a tropical rainy climate zone. The annual temperature ranges between 25 °C and 32°C, with the mean annual temperature is 28 °C.

Figure 1. Study site (a) in Sumatra Island, Indonesia (b).
This region has two peaks of precipitation, in October – November and in March to May, which are associated with the southward and northward movement of the inter-tropical convergence zone (ITCZ) [1]. The main land covers in the study site area include forested peatland, oil palm, shrub, ferns plants, agriculture, and open water.

2.2. Data sources and field measurements

For the investigation, an ALOS 2/PALSAR has been used. PALSAR provides an L-band SAR data and almost monthly temporal resolution for all weather, day and night observations. PALSAR with a dual polarimetry and a full polarimetry are two of the five different science data modes in which PALSAR can operate with the polarization of HH, HV, VV, and VH. The data were retrieved from PASCO Geospatial Group (http://en.alos-pasco.com) with time acquisitions of 11 February 2017 and 25 March, respectively for a dual and a full polarimetry data with the pixel spacing of 6.25 m. Detailed descriptions of ALOS 2/PALSAR are reported in literatures (e.g., http://www.eorc.jaxa.jp/ALOS-2/en/doc/format.htm).

The study areas were inaccessible due to flooding and lack of transportation facilities. Therefore, sampling sites were selected by field survey considered the accessibility, spatial distribution of inventoried peatland data, and area of each class. A total of 5-separated sampling sites were selected. Each sampling site (segment) with 1.5-km quadrants was recognized as discrete areas dominated by the same land cover types. The in-situ data were collected during the field campaigns from 4 May to 16 May 2017. The volumetric soil water content (SWC) of the top 5-cm layer and the top 10-cm layer were measured with Soil Moisture Meter Model: PMS-714. To avoid diurnal variation of SWC as the effect of soil temperatures and respirations, we set the time of the measurements in the morning between 07h and 10h local time. The numbers of chosen measurement points were equal to 250. The geographic coordinates were recorded using a Global Positioning GPS receiver with the accuracy of 5 m. Type of peatlands, as well as vegetation cover in each sites have been described during the field surveys (Table 1). In addition, air temperature and precipitation were measured at height of 1.5 m at three locations, namely Station R1 (101.81° E, 1.60° N), Station T1 (102.95° E, 0.86° N) and station T2 (102.80° E, 0.93 N). Hourly means of air temperature and precipitation which were measured at interval of 10 min, were recorded with a data logger (Campbell Scientific Inc., USA).

| Site Name | Latitude (deg-min-s) | Longitude (deg-min-s) | Elevation (m) | Peat conditions (peat depth*) | Dominant vegetation covers |
|-----------|----------------------|-----------------------|--------------|-----------------------------|---------------------------|
| A1        | 102°07'46.9"E        | 1°08'40.9"N           | 5.834        | Disturbed and no/less peat  | Oil palm                  |
| A2        | 102°10'07.0"E        | 1°09'56.2"N           | 7.104        | Disturbed and thick peat (3.46 m) | Shrubs / fern plants, oil palm, and agriculture (pineapples) |
| D2        | 102°08'25.3"E        | 0°58'46.5"N           | 11.934       | Disturbed and thick peat (3.68 m) | Oil palm, Shrubs         |
| E1        | 102°12'19.9"E        | 0°55'16.0"N           | 8.391        | Disturbed and thick peat (4.91 m) | Oil palm, Shrubs         |
| J1        | 102°15'55.3"E        | 0°40'00.5"N           | 12.152       | Undisturbed and thick peat (> 7.6 m) | Peat swamp forest        |

* averaged peat depth which measured by coring
2.3. Data Analysis

2.3.1. SAR analysis. Speckles found in SAR data due to random multiplicative noise can be recognized by the random pattern and the noise levels increase with average grey level of specified window area in an image scene. The speckle effects can be minimized using adaptive filter and convolution filters. In this study, we used Lee Refined Filter with a 7 x 7 sliding window owing to high contrast areas. Furthermore, the raw Digital Number (DN) values of each pixel in SAR image were transformed to normalized backscattering coefficients ($\sigma^o$), expressed in dB, according to the following equation:

$$\sigma^o = 10 \times \log_{10}(DN^2) + CF$$

(1)

where CF is the calibration coefficient for PALSAR standard products, and equal to -83 dB [16]. Prior to speckles filtering, the data had been georeferenced using the coordinated provided by the header. All the processes for ALOS 2/ PALSAR image calibration and filter were performed using Sentinel Application Platform (SNAP) (Version 5.0).

2.3.2. Soil Moisture. Near-surface soil moisture can be approximated from PALSAR data by using Dubois Model [5]. The model has two questions that relate to the radar backscatter to sensor and soil parameters; one applicable for H-H polarized data, and the other for V-V polarize data, as shown below:

$$\sigma^o_{HH} = 10^{2.75 \cos \theta^{1.5} \sin \theta^5} \times 10^{0.28 \varepsilon \tan \theta (kh \sin \theta)^{1.4} \lambda^{0.7}}$$

(2)

$$\sigma^o_{VV} = 10^{2.5 \cos \theta^3 \sin \theta^3} \times 10^{0.46 \varepsilon \tan \theta (kh \sin \theta)^{1.1} \lambda^{0.7}}$$

(3)

where $\sigma^o_{HH}$, and $\sigma^o_{VV}$ are respectively the horizontally emitted–horizontally, and the vertically emitted–vertically received radar backscattering value (dB), $\theta$ is the incidence angle (37°), $k$ is the free space wave number given by $k = 2\pi/\lambda$, $\lambda$ is the free space wavelength (23.5 cm), $\varepsilon$ is the real part of the dielectric constant, and $h$ is the RMS height at the surface. As mentioned above, this model has been derived from bare soil measurements, but is also applicable to a moderately dense vegetation cover [5]. The $kh \sin \theta$ can be omitted from the relationship with $\varepsilon_r$ by referencing Equations (2) and (3) [6]:

$$\varepsilon_r = \frac{1}{\tan(\theta_{0.0305})} \log_{10} \left( 10^{2.4 \left( \frac{\sigma^o_{VV}}{\sigma^o_{HH}} \right)^{2.77} \cos(\theta)^{-2.3} \sin(\theta)^{-1.2} \lambda^{-0.19}} \right)$$

(3)

and the volume soil moisture percentage (mv) were estimated using scattering model of the inter-compared Dubois – Oh [17]:

$$mv = -5.3 \times 10^{-2} + 2.92 \times 10^{-2} \varepsilon - 5.5 \times 10^{-4} \varepsilon^2 + 4.3 \times 10^{-6} \varepsilon^3$$

(4)

To minimize the influence of roughness and shape of surface to SAR backscattering, we used 3x3 windows moving average of estimated soil moisture.

3. Results and Discussion

3.1. Profile of SAR backscatter and Precipitation in Siak Regency

Figure 2a and Figure 2b show the profile of horizontal-horizontal (HH) polarization and horizontal-vertical (HV) polarization that were derived from a dual mode and a full mode polarization in 5 locations. In general, the backscattering value of a dual mode data was lower than a full mode data. Rainfall or prior the days mainly affected this difference (Figure 2c). During the recording of ALOS 2 (Dual Mode) on 11 February 2017 (DOY 42), precipitation was relatively low with a 6.5 mm-rainfall...
of 10 February 2017 (DOY 41), whereas the precipitation was relatively high during the recording of the Full-mode data on 25 March 2017 (DOY 84). Precipitation of 13.5 mm and 31.5 mm were occurred on 22 March 2017 (DOY 81), and 24 March 2017 (DOY 83), respectively. In addition, precipitation was low during field measurements. A 2 mm- and a 24.5 mm-rainfall were measured respectively, for 2 May 2017 (DOY 122) and 4 May 2017 (DOY 124). A low difference occurred between HV polarization data, whereas a higher difference occurred on HH polarization. These conditions were suggested due to the strength relationship between HH and soil moisture in the L band [4; 8].

![Figure 2](image-url)

**Figure 2.** Backscatter values of ALOS 2 Palsar with a HH polarization (a) and a HV polarization from a dual mode data (11 February 2017) and a full mode (25 March 2017) in 5 locations along with precipitation (c) in Siak Regency.
3.2. Dielectric constant in Siak Regency

Although the fundamental shortcoming of the Oh and Dubois models in terms of dielectric constant and soil moisture retrieval described as Eq. (3) is that they are valid only for bare or sparsely vegetated soil surfaces, however, in the implementation, this model are used for many real soil surfaces that are covered to some extent by vegetation. Dielectric constant of A2 has a high variance with a 5.3 deviation, whereas the J1 has a low variance with a 2.7 deviation among the segments (Figure 3). These conditions had been resulted from discrepancy of different backscattering on land cover and the heights in each segment (Table 2). Oil palm, pineapple, rubber, and shrubs cover A2 segment while J1 is in the protected national park with an undisturbed peat swamp forest. Meanwhile, D2 segment with land cover of young oil palm and shrubs on a 3.7 m-peat has a high dielectric constant among the segments. This was affected by different total plant among segments [12]. This was affected by land cover height. Oil palm in D2 was relatively lower than in A1 and E1. The average was about 1 m, 4 m, and 3.5 m respectively, for D2, A1 and E1.

Table 2. Dielectric constant of land cover in each site/segment

| Site/Segment | Land cover* | Closed to canal | Oil palm | Oil palm & Shrubs | Pineapple & Shrubs | Rubber & Shrubs | Undisturbed Forest | \(\varepsilon\) Segment |
|--------------|-------------|----------------|----------|------------------|-------------------|-----------------|-------------------|---------------------|
| A1           | 177.9±4.7   |                |          |                  |                   |                 |                   | 177.9±4.7           |
| A2           | 179.3±6.1   | 178.7±3.0      | 184.9±3.0| 174.4±4.0        |                   |                 |                   | 181.1±5.3           |
| D2           | 208.6±4.8   | 206.8±2.7      |          |                  |                   |                 |                   | 207.2±3.4           |
| E1           | 171.7       | 165.4±4.5      |          |                  |                   |                 |                   | 165.6±4.5           |
| J1           | 169.9       |                |          |                  |                   |                 |                   | 166.4±2.7           |

\(\varepsilon\) average ± standard Deviation

\(\varepsilon\) dielectric constant
Table 2 shows the dielectric constant of different land cover in each segment. In general, the dielectric constant of non-peat area was lower than the peat area. The dielectric constants were about 177.9±4.7 and 183.1±3.8 respectively, for the non- and peat area. The non-peat area of A1 with a dominant land cover of oil palm has a 178 – dielectric constant, whereas the peat areas of A2 and D2 have a higher dielectric constant with the ε of 179 and 209, respectively for A2 and D2 segments. The increase in dielectric constant of oil palm in D2 compared to A2 probably resulted from the rapid growth of oil palm under the conditions of moist peat soil. A thick peat contributes to an increasing of soil moisture. In contrast, peat areas of E1 and J1, which their ground mainly covered by thick-leaf litter and woody debris, have low dielectric constants than in A1. The leaf litter and woody debris contributed to L band backscattering and decreasing the strength of the relationship to soil moisture.

3.3. Soil moisture in Siak Regency

Soil moisture of respective segments was calculated by using the Eq. (4). The estimation was an average of 3x3-moving window data. Figure 4 shows the profile of soil moisture estimations and measurements in in different land cover types, both in non-peat and peat area. Despite of different acquisition date between measurements and ALOS, soil moisture in non-peat area was lower than in peat area. Moreover, it relatively varied by 2.6%, 4.4%, and 3.5% in peat areas respectively, for ALOS, the measurements at 5-m, and 10-m depth, and was higher than in non-peat areas. Derived soil moisture in peat areas from ALOS ranges from 12.4% to 24.6% with mean value 20.1% (±5.4), whereas in non-peat area, it ranges from 12.6% to 17.1% with mean value 15.4% (±1.0%). Soil moisture measured at 5-cm depth in the peat area has a range between 7.3% and 22.1% with mean value 15.4% (±4.6%), and a range of 12.0% - 23.9% with mean value 19.4% (±3.4%) at 10-cm depth, whereas in non-peat at the 5-cm (10-cm) depth, it ranges between 2.3% and 26.5% (7.5% and 22.5%) with the mean value 11.9% (13.9%) and standard deviation 5.5% (5.5%).

![Figure 4](image-url)  
*Figure 4. Soil moisture estimations and measurements in different land cover types, both in non-peat area (left panel) and in peat area (right panel) in Siak Regency.*
4. Conclusions

In this study, profiles of dielectric constant derived from ALOS 2 Palsar in non-peat area were lower than in peat area. The profiles were about $177.9\pm4.7$ and $183.1\pm3.8$ respectively, for the non- and peat area. It was correlated with peat conditions, land cover, and the variations in precipitation. In a similar land cover, dielectric constant increases as peat depth decreases. However, in undisturbed forest with a thick peat, the profiles decreased. We estimated soil moisture using backscatter inversion model for bare or sparsely vegetated soil surfaces. The model underestimated the soil moisture in sparsely vegetated soil surfaces of pineapples.

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Acknowledgements
The Agency and Application and Assessment of Technology (BPPT) funded the field measurements in Siak, Riau Province, Indonesia. This work was supported by BPPT No. 04 Tahun 2017. We thank to JAXA for providing ALOS-2 data through PI. No. 1248002.