Estimation of Dielectric Constant Using A Dual-pol Sentinel-1A in Tropical Peatland

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Abstract. Synthetic Aperture Radar (SAR) is newest remote sensing technology that is not affected by meteorological conditions. This technology is particularly suitable for use in tropical regions such as Indonesia. In tropical peatland, Indonesia becomes the most important countries for peat areas and carbon stocks. However, this tropical peatland forest had been disturbed by fires, and become a national issue and an international issue. In disaster mitigation, identifying the existence of tropical peatland are needed. But this information is very limited. Therefore, we analysed backscattering value of VV and VH polarisation, and estimated dielectric constant from a dual-polarisation Sentinel-1A in Siak Regency, Riau Province, Indonesia. We also measured dielectric constant at four several types of land use (namely, forest, oil palm, shrubs, and agriculture) along with two types of peat conditions. Results indicated that the dielectric constant decreases as the land use become dry. Results show that the profiles of dielectric constant derived from dual-pol Sentinel-1A images have a high similarity to the direct approach using GPR, with a degree of similarity of 87.24%. The averaged dielectric constants of peat are lower than the peat in subtropics area and ranges between 41 and 68.

Keywords: Peatland, Sentinel-1A, SAR, Dielectric Constant, GPR, velocity

1. Introduction

Peat swamp forest is a natural lowland tropical forest that is covered by the trees. The peat swamp forest ecosystem is an important ecosystem for the availability of biodiversity, carbon, and water reservoirs. The peat acts as a sponge that able to absorb and store a large amount of water. The peat in undisturbed peatland can store water about 0.8 - 0.9 m3/m3, whereas in the disturbed peatland, the peat loses its function as water supply and becomes flammable (Prayoto, 2015). This peat is vulnerable to burning and often caused fires mainly in the dry season. These conditions are not just due to regulatory and socioeconomic issues, but also the availability of peat maps that have not been updated, so the stakeholders had difficulty in making policies, decisions, and actions to prevent peat fires. Therefore, information about the existence of tropical peatland is very important for stakeholders as a reference in policy making. Moreover, monitoring peatland is also needed as an effort to mitigate peat fires that often occur in Indonesia.

Remote sensing provides a method for land monitoring, including successional trends, as well as climatic and anthropogenic-induced change (Chavez et al. 2018). In tropic area, land monitoring is quite difficult due to high distributes of cloud and aerosol influences the usability of optical remote
sensing images, whereas active remote sensing (namely, Synthetic Aperture Radar – SAR) is not influenced by cloud and other meteorological conditions (Kushardono, 2012). SAR is particularly suitable to estimate dielectric constant and soil moisture. Millard and Murray (2018) showed that backscatter values of SAR have a strong correlation with soil moisture. It is sensitive to surface soil moisture and becomes a promising alternative to field data campaigns. However, the SAR backscatter is also affected by the presence of spatially variable vegetation and surface roughness.

In this paper, radar scattering mechanisms for peatlands are examined to determine the existence of tropical peatlands. It is known that the electromagnets of a substance can be indicated by the profile of dielectric constant, which has a strong correlation to the magnetic permeability polarization and electric conductivity. Thus, we evaluated dielectric constant from the field using ground-penetrating radar (GPR) and estimated its spatial variation from the Sentinel-1A type C-band Synthetic Aperture Radar.

2. Another section of your paper Material and Methods
2.1. Site Descriptions
The research 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 sites are in a tropical rainy climate zone, with the annual temperature ranges between 25 °C and 32°C. Siak Regency has a total peatland area of 6,436,649 ha with a balanced area from a shallow depth (50 - 100 cm) to a very deep (> 300 cm) (BBSDL, 2014). This region has two peaks of precipitation, in October – November and in March to May (Aldrian and Dwi Susanto, 2003). Dominant land cover at the sites are forested peatland, oil palm, shrub, ferns plants, agriculture, and open water.

Figure 1 Study site (a) in Sumatra Island, Indonesia (b).

2.2. Data sources and field measurements
For the investigation, we used a wide range of Sentinel-1A scenes. We used both the VH and the VV channels with Interferometry Wide (IW) swath mode. The data were retrieved from ESA - the Copernicus program (https://scihub.copernicus.eu) with time acquisitions of 1 May 2017. Detailed descriptions of Sentinel-1A are reported in literatures (e.g., https://sentinel.esa.int/web/sentinel/home).

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 4-separated sampling sites was selected.
Each sampling site (segment) with 1.5-km quadrants was recognized as discrete areas dominated by the same land cover types (Table 1). A2 and J1 were identified as peatland area, whereas A1 and D1 were identified as non-peatland. The in-situ data were collected during the field campaigns from 4 May to 16 May 2017 (Marpaung et al., 2018). We observed subsurface of peat conditions without drilling or digging using ground-penetrating radar (GPR) at the segment of A1, A2 and J1. The GPR instrument is divided into three main parts, namely (i) the acquisition instrument, such as antenna, GPS, and odometer, (ii) the main unit control such as Digital Antenna Driver, and computer unit, and (iii) power supply. In this study, we used an antenna of 80-MHz with the antenna type of un-shielded. This antenna is commonly used for high structure anomaly in subsurface because it is not sensible to the environmental noises. The geographic coordinates were recorded using a Global Positioning GPS receiver with the accuracy of 5 m.

### Table 1. List of site locations and vegetation types

| Site Name | Longitude (deg-min-s) | Latitude (deg-min-s) | Peat Condition (Peat depth*) | Dominant vegetation covers |
|-----------|-----------------------|----------------------|----------------------------|---------------------------|
| A1        | 102°07'46.9"E         | 1°08'40.9"N         | Disturbed and no/less peat | Oil palm                  |
| A2        | 102°10'07"E           | 1°09'56.2"N         | Disturbed and thick peat    | Shrubs/fern plants, oil palm, and agriculture (pineapples) |
| D1        | 102°06'58"E           | 1°09'14.0"N         | Disturbed and no/less peat | Paddy field               |
| J1        | 102°15'55.3"E         | 0°40'00.5"N         | Undisturbed and thick peat  | Peat swamp forest         |

* averaged peat depth that measured by coring

### 3. Data Analysis

#### 3.1. SAR analysis

A random multiplicative noise is commonly found as speckles in SAR data. The noise increases with the average grey level of the specified windows area in an image scene. This noise can be minimized using adaptive filter and convolution filters. In our study, we used Lee Refined Filter with a 7 x 7 sliding windows owing to high contrast areas. Furthermore, the raw Digital Number (DN) values of each pixel in SAR image were transformed to normalized backscattering coefficients ($\sigma^\circ$), expressed in dB, according to the following equation:

$$\sigma^\circ = 10 \times \log_{10}(\text{DN}^2) + \text{CF}$$  \hspace{1cm} (1)

where CF is the calibration coefficient for Sentinel standard products. Prior to speckles filtering, the data had been georeferenced using the coordinated provided by the header. All the processes for Sentinel-1A image calibration and filter were performed using the Sentinel Application Platform (SNAP) (Version 5.0).
3.2. Dielectric constant in SAR
Backscattering coefficients ($\sigma^o$) of the HH and VV polarization images were used to estimate the value of the dielectric constant ($\varepsilon'$) using a Dubois model (Dubois et al., 1995) as follows:

$$\varepsilon' = \frac{\log\left(\frac{\sigma_{HH}^{0.7857}}{\sigma_{VV}^{0.7857}}\right)10^{-3.10}}{\cos^{1.5} \theta \sin \theta \sin \theta \sin \theta \sin \theta}$$

where $\varepsilon'$ is the soil dielectric constant, $\theta$ is the angle formed / incident ($^\circ$), $k = \frac{2\pi}{\lambda}$ with $k$ is the number of waves, $\lambda$ is the wave height with a value of about 23.6 cm. The model has two questions that relate to the radar backscatter between sensor and soil parameters on bare soils; one applicable for H-H polarized data, and the other for V-V polarize data, as shown below:

$$\sigma_{HH}^0 = 10^{2.75} \cos^{1.5} \frac{\theta}{\sin \theta} 10^{0.28} \tan \theta (kh \sin \theta)^{1.4} \lambda^{0.7}$$

$$\sigma_{VV}^0 = 10^{2.5} \cos^2 \frac{\theta}{\sin \theta} 10^{0.46} \tan \theta (kh \sin \theta)^{1.1} \lambda^{0.7}$$

where $\sigma_{HH}^0$ and $\sigma_{VV}^0$ are respectively the horizontally emitted-horizontally, and the vertically emitted-vertically received radar backscattering value (dB), $\theta$ is the incidence angle (± 23.5°; the angle value ranges from 20° to 27°), $\varepsilon$ is the real part of the dielectric constant, and $h$ is the RMS height at the surface which was observed at the sites. This model has been derived from bare soil measurements but is also applicable to a moderately dense vegetation cover (Dubois et al., 1995). Because we used a dual-pol Sentinel with polarimetric features of VH and VV; we analyzed the $h$ prior the calculation of dielectric constant using a statistical approach (Rao et al., 2013). The $h$ was described as a function of the ratio between backscattering values in VH and VV polarization ($h = \sigma_{HH}^0 / \sigma_{VV}^0$) or function of the ratio between backscattering values in HV and HH polarization ($h = \sigma_{VH}^0 / \sigma_{HH}^0$).

3.3. Dielectric constant in GPR
Dielectric constant of a substance such as the peat describes the profile of magnetic permeability polarization and electric conductivity. In the practice, the permeability of the peat is identical in vacuum (Marttilla et al., 1982), while the dielectric constant of a medium is relatively constant (Daniels et al. 1988). Morey (1974) showed that the relative soil dielectric constant ($\varepsilon$) from a GPR measurement is expressed as:

$$\varepsilon = \left(\frac{C}{\tau}\right)^2 = \left(\frac{C_0 \tau}{\sigma}\right)^2$$

where $C$ is the electromagnetic radiation speed (light) in a vacuum (± 0.3 m ns-1), $V$ is the measured wave propagation speed in a medium, $t$ is the wave propagation time (ns), and the $s$ is wave propagation distance (m). The $V$ was analyzed using a Common Mid-Point (CMP) (Annan, 2003).

4. Results and Discussion
4.1. Profile of SAR backscatter and Dielectric Constant in SAR
Figure 2 shows the profile of HH polarization ($\sigma_{HH}^0$) and VV polarization ($\sigma_{VV}^0$) that were derived from a dual-pol of Sentinel-1A at 4 locations in Siak Regency, Riau Province. In general, the $\sigma_{HH}^0$ was relatively two times lower than the $\sigma_{VV}^0$. Meanwhile, the $\sigma_{HH}^0$ and the $\sigma_{VV}^0$ in non-peatland (A1 and D1) were lower than in peatland (A2 and J1). In the non-peatland, the $\sigma_{HH}^0$ and the $\sigma_{VV}^0$ were -13.80±0.82 (-6.49±0.97) and -18.68±1.94 (-10.93±2.04), respectively, for A1 and D2, whereas in the peatland, the $\sigma_{HH}^0$ and the $\sigma_{VV}^0$ were -13.18±1.26 (-7.33±1.22) and -12.95±1.02 (-7.11±1.11), respectively, for A2 and J1. The backscatter value of the D1 was relatively lower than the other segments. This is affected by water, where the area was a paddy field with the first vegetative phase.

In SAR images, the backscattering profiles strongly related to surface roughness, and consequently related to the dielectric constant of the surface. The profile of dielectric constant is shown in Figure 3. It shows that A1 which was identified as a non-peat area with a less peat has a lower dielectric constant than the peat area of A2 and J1. However, the dielectric constant of D1 is relatively similar to the peat area of A2 and J1. This profile may be affected by a low surface roughness. It is reported that (Putiamini et al., unpublished) the surface roughness that was denoted as a ratio of polarimetric features ($\sigma_{HH}^0/\sigma_{HH}^0$) ranges between 1.5 and 2.5 in Siak Regency. The range covered over 95% of the data in each segment. Within the ratio, the A1 has a dominant dielectric constant of 35.90 with a high dominant ratio of 1.4 to 3, while the D1 has a dominant dielectric constant of 53.81 at a dominant ratio of 1.2 to 2.5. The dominant dielectrics in the peat area study were 49.18 and 53.76 with a dominant ratio relatively similar to the D1, respectively, for A2 and J1. Moreover, the averaged dielectric constant ranges from 36.61 to 53.82 with a dominant ratio of 1.2 to 2.5 (Table 2).
4.2. Modelling Dielectric Constant in Siak Regency

In theory, dielectric constant derived from SAR and GPR have similar velocity at the medium/substance. This velocity describes physical characteristics of the media. The propagation velocity derived from the GPR using the CMP model and the estimated velocity of Sentinel-1A is shown in Table 2. It shows that the dielectric constant and the propagation velocity of peat that derived from SAR are relatively similar to the GPR. The degree of similarity is 87.24%. These indicate that the dielectric constant and the velocity of a peat can be estimated using a dual-pol Sentinel-1A image without having a direct approach using GPR. On the other hand, the dominant/averaged dielectric constant of peat in Siak Regency is relatively lower than the dielectric constant of peat in the subtropics. The dielectric constant of peat in subtropics ranges between 60 and 80 (Hanninen, 1992) where in Siak, it ranges between 41 and 64.

Table 2. Averaged Dielectric constant and velocity derived from Sentinel-1A and GPR at 4 locations in Siak Regency

| Segment | Sentinel-1A | GPR |
|---------|-------------|-----|
|         | ε'          | ν   | ε'     | ν     |
| A1      | 36.60       | 0.050 | -  | 0.048 |
| A2      | 53.73       | 0.042 | 52.57 | 0.036 |
| D1      | 52.82       | 0.040 | -  | -     |
| J1      | 53.59       | 0.040 | 51.02 | 0.044 |

ε' dielectric constant
ν propagation velocity (m ns⁻¹)

5. Conclusions

In this study, profiles of dielectric constant derived from dual-pol Sentinel-1A imagery was affected by the land use profile. It decreased as the land use becomes dry. Furthermore, the profiles have a high similarity to the direct approach using GPR, with a degree of similarity of 87.24%. The averaged dielectric constants of non-peat (A1) is 36.6, while in the peat area; the value is lower than the peat in subtropics area and it ranges between 41 and 64. However, this study was limited due to a low sample data. Therefore, future analysis with more sampling data at different tropical peat types are needed.
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