Profile of dielectric constant of peat in Ogan Komering Ilir Regency, Indonesia using SAR Sentinel-1 and ground penetrating radar

F Marpaung1, Sumirah1, L Sumargana1, and D Nugroho1

1Agency for the Assessment and Application of Technology (BPPT) Jakarta 10340, Indonesia
fiolenta.marpaung@bppt.go.id*

Abstract. Profile of dielectric constant of a substance or a surface indicates its electromagnetic parameters. The profile is associated with electric polarization, permeability with magnetic polarization, and conductivity with an electric current field. In the practice, the Synthetic Aperture Radar (SAR) and the Ground Penetrating Radar (GPR) are commonly utilized to determine how much velocity of a substance and its scattering profiles. However, information about the profile radar scattering mechanisms in tropical peatland is still limited. Therefore, we evaluated dielectric constant from the field using GPR and estimated its spatial variation from a dual-polarization Sentinel-1A type C-band SAR in Ogan Komering Ilir, South Sumatera Province, Indonesia. We measured dielectric constant at the two major types of land use, namely oil palm and acacia. Results indicated that the dielectric constant derived from SAR Sentinel-1A and GPR are affected by peat moisture. It increases as the peat moisture increases. Results show that during peat dry conditions, the profiles of dielectric constant derived from dual-pol Sentinel-1A images are relatively similar to the dielectric constant of peat in Siak Regency. It ranges between 31.78 and 59.3. The dielectric constant derived from GPR ranges between 69 and 70.

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

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 m$^3$ m$^{-3}$, whereas in the disturbed peatland, the peat loses its function as water supply and becomes flammable [1]. 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 an output of reference for policy decision 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 [2]. In the tropics, 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 [3]. SAR is particularly suitable to estimate dielectric constant and soil moisture. Millard and Murray [4] showed that the SAR backscattering coefficients 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. Material and Methods

2.1. Site Descriptions
In the study, the sites (1.275 °N, 100.906 °E – 0.347 °N, 102.183 °E) are located at two different types of land use in Ogan Komering Ilir (OKI) Regency, South Sumatera Province, Indonesia (Figure 1, Table 1). The sites are in a tropical rainy climate zone, with the annual temperature ranges between 25 °C and 32°C. This region has low rainfall in October and high rainfall in February – March. The land use dominantly covered by oil palm and acacia.

![Figure 1. Study site](image)

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 2018. Detailed descriptions of Sentinel-1A are reported in the literature (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 5-separated sampling sites was selected during field campaigns from 24 April to 4 May 2018. Each sampling site with 0.350-km squares was recognized as discrete areas dominated by the same land cover types (Table 1). We also observed subsurface of peat conditions without drilling or digging using ground-penetrating radar (GPR) and with coring in all sample sites. 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 with the centre of the frequency of 80-MHz and the effective bandwidth is between 40 MHz and 120 MHz, with the antenna type of un-shielded. This antenna is commonly used for high structure anomaly in a 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 sample data

| Sample Code | Longitude | Latitude | Administrative Division | Weather Conditions | Land cover |
|-------------|-----------|----------|-------------------------|--------------------|-----------|
| KYG12       | 104.950   | -3.480   | Kayu Agung              | After rain (wet)   | Oil Palm  |
| KYG 13      | 104.950   | -3.485   | Kayu Agung              | After rain (wet)   | Oil Palm  |
| KYG 14      | 104.953   | -3.490   | Kayu Agung              | After rain (wet)   | Oil Palm  |
| PYB 02      | 105.369   | -3.051   | Peyambungan             | Dry                | Acacia    |
| PYB 15      | 105.388   | -3.062   | Peyambungan             | Dry                | Acacia    |

2.3. Data Analysis

2.3.1. SAR analysis

Random multiplicative noises are 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 were then transformed to normalized backscattering coefficients ($\sigma^o$), expressed in dB, according to the following equation:

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

where CF is the calibration coefficient for Sentinel standard products. Prior to speckles filtering, the data had been georeferenced using the coordinates provided by the header. All the processes for Sentinel-1A image calibration and filter were performed using the Sentinel Application Platform (SNAP) (Version 6.0).

2.3.2. 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 [5] as follows:

$$\varepsilon' = \log\left(\frac{\sigma_{HH}^o}{\sigma_{VV}^o}\right) \times 10^{-0.028 \varepsilon \cos^{1.82} \theta \sin^{0.93} \theta} \times 10^{0.15}$$  \hspace{1cm} (2)

where $\varepsilon'$ is the soil dielectric constant, $\theta$ is the angle formed / incident (°), $k = 2\pi/\lambda$ 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:

$$\sigma_{HH}^o = 10^{2.75 \cos^{0.3} \sin^{1.5} \theta} \times 10^{0.28 \varepsilon \tan \theta (k h \sin \theta)^{1.4} \lambda^{0.7}}$$  \hspace{1cm} (3)

$$\sigma_{VV}^o = 10^{2.5 \cos^{0.3} \sin^{3} \theta} \times 10^{0.46 \varepsilon \tan \theta (k h \sin \theta)^{1.1} \lambda^{0.7}}$$  \hspace{1cm} (4)

where $\sigma_{HH}^o$ and $\sigma_{VV}^o$ are respectively the horizontally emitted-horizontally, and the vertically emitted-vertically received radar backscattering value (dB), $\theta$ is the incidence angle ($\approx 23.5^\circ$; 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 [6]. Because we used a dual-pol Sentinel with polarimetric features of VH and VV; we analyzed the $h$ and then calculate dielectric constant using a statistical approach [6]. The $h$ then described as a function of the ratio between backscattering values in
VH and VV polarization \( (h = \sigma_{VH}^0/\sigma_{VV}^0) \) or the ratio between backscattering values in HV and HH polarization \( (h = \sigma_{HH}^0/\sigma_{VH}^0) \).

2.3.3. Dielectric constant in GPR

The 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 a vacuum, while the dielectric constant of a medium is relatively constant \([7]\). Morey \([7]\) showed that the relative soil dielectric constant \((\varepsilon)\) from a GPR measurement is expressed as:

\[
\varepsilon = \left(\frac{c}{v}\right)^2 = \left(\frac{C + t}{s}\right)^2
\]

where \(C\) is the electromagnetic radiation speed (light) in a vacuum \((\approx 0.3 \text{ m ns}^{-1})\), \(V\) is the measured wave propagation speed in a medium, \(t\) is the wave propagation time (ns), and \(s\) is wave propagation distance (m). The \(V\) was analyzed using a Common Mid-Point (CMP) \([8]\).

3. Result and Discuss

3.1. Profile of SAR backscatter and Dielectric Constant in SAR

\[\text{Figure 2. Backscatter values of Sentinel-1A with a VH polarization and a VV polarization from a dual mode data (1 May 2018) in 5 locations in Ogan Komering Ilir (OKI) Regency, South Sumatera Province, Indonesia.}\]

Figure 2 shows the profile of VH polarization \( (\sigma_{VH}^0) \) and VV polarization \( (\sigma_{VV}^0) \) that were derived from a dual-pol of Sentinel-1A at 5 locations in OKI Regency, South Sumatera Province. In general, the \( \sigma_{VH}^0 \) was relatively two times lower than the \( \sigma_{VV}^0 \). The \( \sigma_{VH}^0 \) was relatively similar among the segments. In the Kayu Agung District, the \( \sigma_{VH}^0 \) and the \( \sigma_{VV}^0 \) were \(-13.23\pm0.40\) \((-9.17\pm0.25)\), \(-13.34\pm0.30\) \((-6.79\pm0.28)\), and \(-13.51\pm0.48\) \((-9.73\pm0.31)\) respectively, for KYG12, KYG13, and KYG14, whereas in the Peyambungan District, the \( \sigma_{VH}^0 \) and the \( \sigma_{VV}^0 \) were \(-13.20\pm0.27\) \((-7.21\pm0.69)\) and \(-13.34\pm0.19\) \((-6.44\pm0.26)\) respectively, for PYB02 and PYB15. Although the measured peat soil moisture in Kayu Agung District was relatively high than in Peyambungan District, the \( \sigma_{VV}^0 \) of KYG13 were higher than in Kayu Agung District (KYG12 and KYG14). This is affected by oil palm canopies, where the sensitivity of C-band SAR in penetration is limited through its canopies.

In SAR images, the backscattering profiles strongly related to surface roughness, and consequently related to the dielectric constant of the surface. Profile of the dielectric constant is shown in Figure 3. It shows that PYB02 and PYB15 which were identified an acacia plantation area with low soil moisture have a low dielectric constant than the peat area of KYG12 and KYG14. Surface roughness that was
denoted as a ratio of polarimetric features \( \frac{\sigma_{VH}^0}{\sigma_{VV}^0} \) ranges between 1.4 and 2.0. Within the ratio, the dielectric constant ranges from 35.77 to 88.36 (Table 2). The Kayu Agung area has a dielectric constant of 70.21±4.48 and the Peyambungan area has a dominant dielectric constant of 42.22±7.31. The dielectric constants of peat in the Kayu Agung were relatively similar to the peat with a land cover of oil palm in Siak Regency [9].

![Figure 3](image-url)  
**Figure 3.** Dielectric constant of Sentinel-1A – Dual Mode at 5 segments in Ogan Komering Ilir (OKI) Regency, South Sumatera Province.

### 3.2. Dielectric Constant in Ogan Komering Ilir Regency

Velocity at the medium/ substance describes the 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 constants derived from SAR in Kayu Agung are relatively higher to the GPR. However, the values derived from SAR in Penyabungan are lower to the GPR. The dielectric constant in Peyambungan with a low measured peat moisture ranges from 31.78 to 59.3. These were relatively similar to the dielectric constant of peat in Siak Regency [10] with the ranges of 41 to 64. However, the propagation velocity derived from GPR in Kayu Agung was slightly higher than in Peyambungan and results in a slightly low dielectric constant of peat in Kayu Agung than in Peyambungan. These conditions indicate that the dielectric constant of peat derived from SAR are strongly affected by the wetness condition of peat. Dielectric constant increased as the wetness condition of peat increased. During a dry peat condition, dielectric constants of tropical peatland both from Siak Regency, and the Penyabungan District in Ogan Komering Ilir Regency are relatively lower than the dielectric constant of peat in the subtropics, which ranges between 60 and 80 [11].

| Segment | Sentinel-1A | GPR |
|---------|-------------|-----|
|         | \( \varepsilon' \) | \( \nu \) | \( \varepsilon' \) | \( \nu \) |
| KYG12   | 81.50±3.94  | 0.033±0.001 | - | - |
| KYG13   | 40.78±4.11  | 0.047±0.002 | - | - |
| KYG14   | 88.36±5.38  | 0.032±0.001 | 69.06 | 0.03610 |
| PYB02   | 48.67±10.63 | 0.043±0.005 | - | - |
| PYB15   | 35.77±3.99  | 0.050±0.003 | 69.64 | 0.03595 |

\( \varepsilon' \) dielectric constant  
\( \nu \) propagation velocity (m ns\(^{-1}\))
4. Conclusions
In this study, profiles of dielectric constant derived from dual-pol Sentinel-1A imagery and GPR were affected by peat moisture. The propagation velocity derived from GPR in Kayu Agung was slightly higher than in Peyambungan and results in a slightly low dielectric constant of peat in Kayu Agung than in Peyambungan. In dry peat conditions, the dielectric constant derived from SAR in Peyambungan ranges from 31.78 to 59.3 and were relatively similar to the dielectric constant of peat in Siak Regency with the ranges of 41 to 64. The dielectric constants of tropical peatland both from Siak Regency, and the Penyabungan District in Ogan Komering Ilir Regency are relatively lower than the dielectric constant of peat in the subtropics.

5. Acknowledgements
This research was supported by the Agency for the Assessment and Application of Technology (BPPT). We thank our colleagues from the Center for Regional Resources Development of Technology (PTPSW) who provided field data, insight and expertise that greatly assisted the research.

6. References
[1] Prayoto, Analisis Kebakaran Hutan dan Lahan Gambut Provinsi Riau Tahun 2014. 2015.
[2] Bourgeau-Chavez L L, E.S.L., Graham J A, Hribljan J A, Chimner R A, Lillieskov E A, Battaglia M J, Arbor A, Mapping Peatlands in Boreal and Tropical Ecoregion. Comprehensive Remote Sensing 6 2018.
[3] Kushardono, D., Klasifikasi Spasial Penutup Lahan Dengan Data Sar Dual-Polarisasi Menggunakan Normalized Difference Polarization Index Dan Fitur Keruangan Dari Matrik Kookurensi (Spatial Land Cover Classification Using Dual-Polarization Sar Data Based On Normalized Difference Polarization Index And Spatial Features From Co-Occurrence Matrix). Jurnal Penginderaan Jauh dan Pengolahan Data Citra Digital, 2012. 9(1).
[4] Millard, K. and M. Richardson, Quantifying the relative contributions of vegetation and soil moisture conditions to polarimetric C-Band SAR response in a temperate peatland. Remote sensing of environment, 2018. 206: p. 123-138.
[5] T, D.P.C.V.J.J.E., Measuring Soil Moisture with Imaging Radars. IEEE transactions on geoscience and remote sensing. 1995: p. 33.
[6] Rao, S.S., et al., Modified Dubois model for estimating soil moisture with dual polarized SAR data. Journal of the Indian Society of Remote Sensing, 2013. 41(4): p. 865-872.
[7] Dallaire, P.-L., and M. Garneau. The use of a ground-penetrating radar (GPR) to characterize peat stratigraphy and estimate the carbon pool in a boreal peatland, Eastmain region, James bay, Quebec, Canada. in Proceedings, 12th International Conference on Ground-Penetrating Radar. University of Birmingham, UK. 2008.
[8] P, A.A., Ground Penetrating Radar Principles, Procedure & Applications, Sensors & Software (Canada: Inc. Mississauga). 2003.
[9] Putiamini, S., F. Marpaung, and D. Fernando. Estimation of Peatland Distribution Using Ratio Dual-pol from Sentinel-1A. in IOP Conference Series: Earth and Environmental Science. 2019. IOP Publishing.
[10] Marpaung, F., et al. Estimation of Dielectric Constant Using A Dual-pol Sentinel-1A in Tropical Peatland. in IOP Conference Series: Earth and Environmental Science. 2019. IOP Publishing.
[11] P, H., Geological Survey of Finland, Application of Ground Penetrating Radar and Radio Wave Moisture Probe Techniques to Peatland Investigation (Findland: Vammala). 1992.