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A method to estimate tree trunk diameter and its application to discriminate Java-Indonesia tropical forests

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Abstract. A numerical method was used to analyse the interaction of L-band microwaves with the trunks of four species of Java-Indonesian trees. These species were teak (*Tectona grandis*), pine (*Pinus merkusii*), mahogany (*Swietenia macrophylla*) and rasamala (*Altingia exelsa*). This method approximated a tree trunk as an infinite length of three layers of cylindrical dielectric media. The horizontal polarisation of the scattered wave was derived in order to calculate the relationship between tree trunk diameter and backscattering coefficient. The analysis result was confirmed by simulating the scattering problems on trunk using the Finite Difference Time Domain (FDTD) method. Both analysis and simulation results were similar. This relationship was used to estimate trunk diameters from JERS-1 SAR data.

1. Introduction

Recently, remote sensing technology has been an efficient and helpful tool to monitor tropical forests in a large area. The main problem in monitoring tropical areas is cloudy conditions. The best instrument to monitor these areas is Synthetic Aperture Radar (SAR), as it works effectively in spite of cloudy conditions. However, SAR images are not easily interpreted due to the complex relations of the radar backscattering mechanisms between microwaves and vegetation types. Many researchers developed electromagnetic modelling of vegetations (e.g. Sarabandi 1989, Li *et al.* 1999). On the other hand, nobody has attempted to find relationships between the radar backscattering coefficients and the characteristics of tropical forest vegetation, particularly species that are found in Indonesian tropical forests.

In this study, the analysis of scattering problems on trunks has been done in order to estimate the relationship between diameters of tree trunks and its backscattering coefficients. Then the possibility of this relationship to estimate the trunk diameters of rasamala (*Altingia exelsa*) from the Japanese Earth Resources Satellite (JERS-1) SAR image is evaluated.

2. Theory and simulation

Three layers of dielectric media namely xylem, skin and heartwood compose the tree trunk (Sarabandi 1989). In this study, the dielectric constants of each layer of four species of Java-Indonesian trees were measured using dielectric probe kit HP85070B, and results of the measurement are shown in the table 1. Then a tree

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Table 1. Dielectric constants of Indonesian tropical forest trees.

	Skin		Xylem	
Species names	ε_r'	ε_r''	ε_r'	ε_r''
Teak	3.1	0.4	11.5	2.6
Mahogany	2.7	0.3	10.2	2.1
Pine	3.4	0.4	13.6	3.0
Rasamala	2.5	0.3	9.4	2.1

trunk was approximated as an infinite length of three layers of cylindrical dielectric media. Figure 1 shows geometry of analysis, where A, B and C are layers namely xylem, skin and heartwood with radius a, b and c, respectively. Several trunks of rasamala trees were measured and the results showed that each component had relations $c=0.1b$ and $a=0.8b$. Consider ϕ is the angle between the x-axis and the reflection direction to the observed point, and ρ is the distance from trunk centre to the observed point. To simplify the analysis, heartwood was defined as a perfect conductor. E_ϕ^I and H_z^I are incident electric and magnetic fields, respectively.

Here the scattered fields of the trunk were calculated due to a transverse magnetic mode of incident plane wave propagating in $-x$ direction. Suppose that the scattered electric field is

$$E_\phi^s = E_0^I \sum_{m=0}^{\infty} b_m H_m^{(2)\prime}(k_0\rho)\cos m\phi \tag{1}$$

where E_0^I and k_0 are the amplitude coefficient and wave number of the incident wave, respectively, $H_m^{(2)}$ is the second kind m order of Hankel function, the superscript prime denotes the differentiation of function, and b_m is the amplitude coefficient derived as

$$b_m = U_m j^m \frac{[k_0 b\alpha_{6m} J_m'(k_0 b) - (b\mu_0\alpha_{7m} - \alpha_{6m})J_m(k_0 b)]}{(b\mu_0\alpha_{7m} - \alpha_{6m})H_m^{(2)}(k_0 b) - \alpha_{6m}k_0 b H_m^{(2)\prime}(k_0 b)} \tag{2}$$

where $m=0, 1, 2, \ldots$, then α_{6m} and α_{7m} are constants, U_m is 1 for $m=0$ and 2 for $m>0$. The amplitude coefficient of the scattered wave from the perfectly conductor

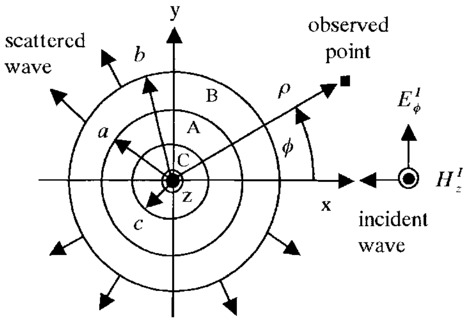

Figure 1. Geometry of analysis.

(C layer) is calculated similarly and obtained as

$$b_m = - U_m j^m \frac{J_m(k_0 c)}{H_m^{(2)'}}(k_0 c) \tag{3}$$

Now by substituting each b_m into equation (1), the scattered power of the cylindrical trunk and perfect conductor could be calculated, and then the backscattering coefficient was derived by its reflection loss.

To confirm the analysis results, simulation of scattering problems on trunks using Finite Difference Time Domain (FDTD) method (Yee 1966, Toru 1998) were done. Considered the following, the computation domain was 300 grids × 300 grids, space and time increments were $\Delta x = \Delta y = 0.0125$ m and $\Delta t = 2.5 \times 10^{-11}$ s, respectively and running time was $t = 1200\,\Delta t$ s. The incident wave was a plane wave, and field amplitudes used Gaussian pulse. When time-domain electromagnetic field equations were solved using finite-difference techniques in unbounded space, Mur method (Mur 1981) was used as absorbing boundary condition to limit the domain in which the fields were computed.

Figure 2 shows the scattered wave on the trunk of rasamala (radius $b = 0.5$ m) with running time $t = 300\Delta t$ s and assumed $\phi = 0°$ and $\rho = 1.5$ m. The Fast Fourier transform was employed to obtain the electric field intensities of preferred frequency ($f = 1.275$ GHz). Finally, the backscattering coefficients were calculated and compared with the analysis results as seen in figure 3. This figure shows that analysis results were in good agreement with simulation results.

3. The study area

The study area was Cisarua tropical forest, part of Gede Pangrango National Park, west Java, Indonesia. This area is one of the wettest parts of Java with an

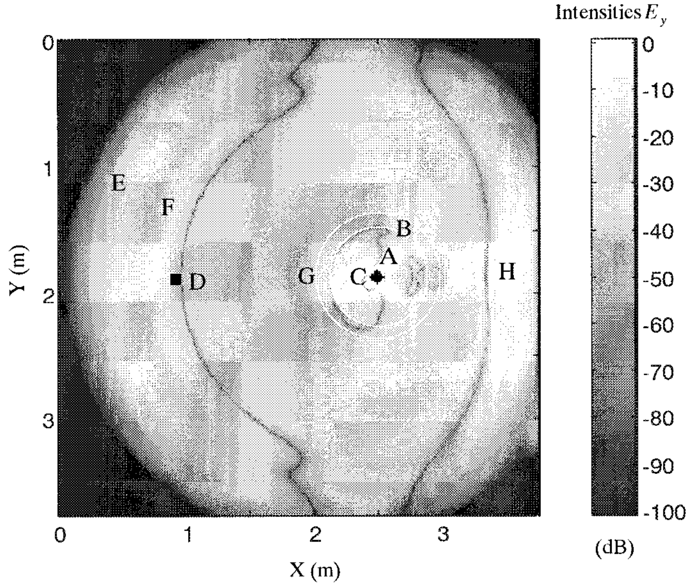

Figure 2. Scattered wave on tree trunk (radius $b = 0.5$ m) with running times $t = 300\,\Delta$s. Remarks A: xylem; B: skin; C: heartwood; D: observed point; E, F, and G are scattered wave from skin, xylem, and heartwood, respectively; H: forwarded wave.

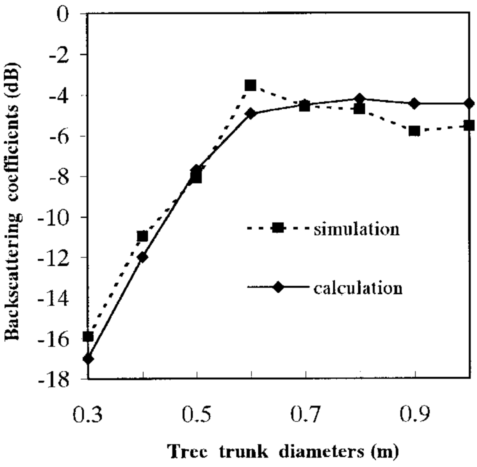

Figure 3. Comparison between calculation and simulation results.

average annual rainfall of around 3000 mm to 4200 mm, while the relative humidity varies between 80% and 90%. The region, as seen in figure 4, has altitude ranging from 627 m to 2030 m. Biomes of this area are the sub-montane (1100 m to 1500 m) and montane (1500 m to 2030 m) tropical forest. In addition to that, settlement and paddy fields called *ladang* are distributed in the region with altitude between 627 m and 1100 m above sea level. Tea, which has tall canopy about 1m, is usually planted at altitude between 627 m and 2030 m by government companies.

The sub-montane tropical forest has the highest diversity of plant life and is characterized by large trees forming diameter trunks between 0.3 m and 0.4 m. The dominant species in this ecosystem is rasamala. The ground data revealed that this species grow about 3 m from each other. Besides a rich ground flora containing begonias and ferns, many species of epiphytes are found growing non-parasitically on twigs and branches (e.g. orchids, lianas, and herbs).

Montane tropical forest has a lower diversity of plants with fewer herb species than the sub-montane zone. Common trees included rasamala; also noticeable are puspa (*Schima walichii*) and conifers (*Dacrycarpus imbricatus* and *Podacarpus neriifolius*).

4. Image processing and analyses

The JERS-1 SAR image was examined in order to estimate the diameters of rasamala in the study area. The image (path 107, row 312) was acquired on 10 August 1997 during the dry season in the study area. This image was processed at level 2.1 or standard geocoded image and was resampled to Universal Transverse Mercator (UTM) projection by the Earth Observation Research Centre (EORC) of National Space Development Agency (NASDA) of Japan. Firstly, a 3 × 3 median filter was employed and the second process used a 5 × 5 average filter to reduce inherent speckle noise (Sunar *et al.* 1998). At the same time, the image was also referenced to the UTM co-ordinate system, through a polynomial rectification using 30 ground control points collected from topographic maps scale of 1:25 000 (BAKOSURTANAL 1990). This procedure yielded a geometric accuracy of 0.1 pixels. Then the spatial resolution of SAR image was resampled to 12.5 m.

A supervised classification was performed to classify the image. The study area

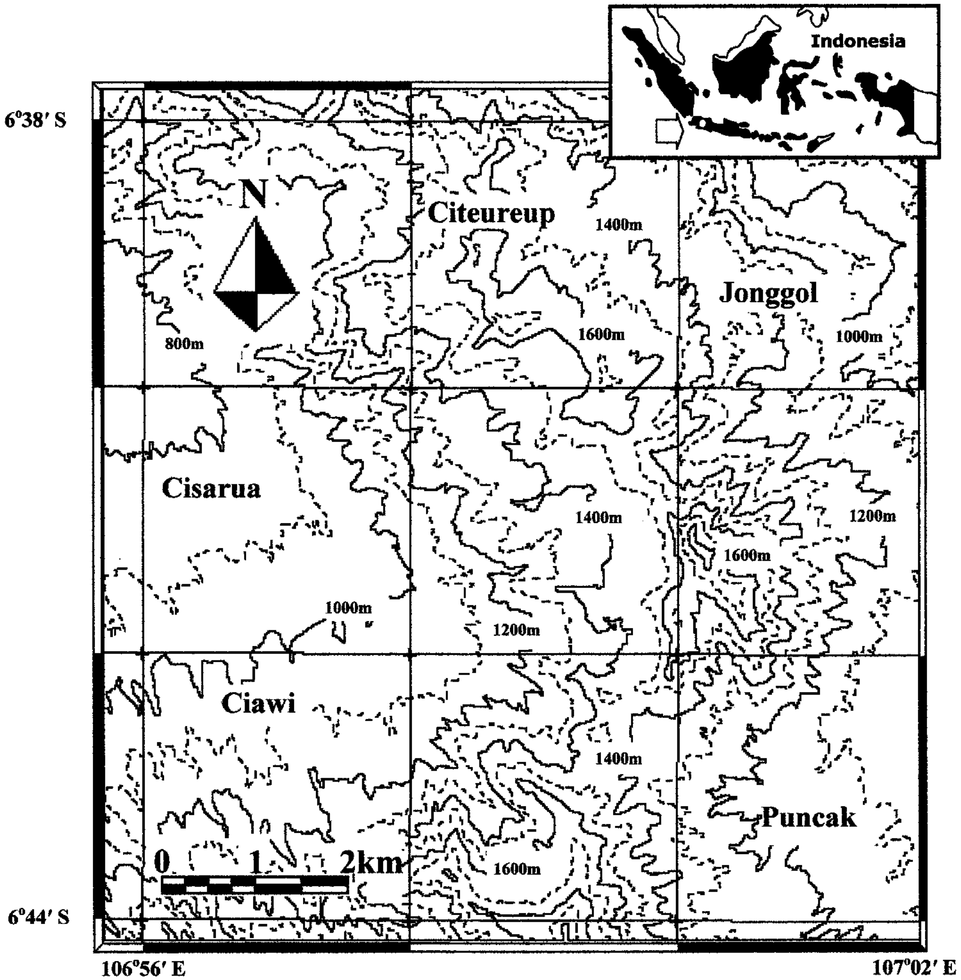

Figure 4. Location of the study area.

was classified into six classes based on topographic maps (BAKOSURTANAL 1990). They were namely forest 1, forest 2, forest 3, bush (tea), *ladang*, and settlement. Figure 5 shows classification results and the terrain characteristics of each ecosystem zone in the study area. The classification results contained only 1% error in comparison with the 30 training sites that were sampled from topographic maps. The terrain characteristics of the study area were generated using digital elevation model (DEM 1990). Figure 5 shows that forest classes distributed in the study area are at the altitude above 1100 m or at the sub-montane and montane zones.

The statistical value of each forest class was derived and then the backscattering coefficient of each class was calculated using NASDA calibrated equation (Shimada 1998). These results are shown in table 2. Figure 6 shows the analysis results for each species, obtained by substituting JERS-1 SAR specification parameters to derived equations. The species included in forest classes in each pixel were assumed to be rasamala, because it was the dominant species in the study area. By comparing the backscattering coefficient of each forest class to the curve of rasamala in figure 6,

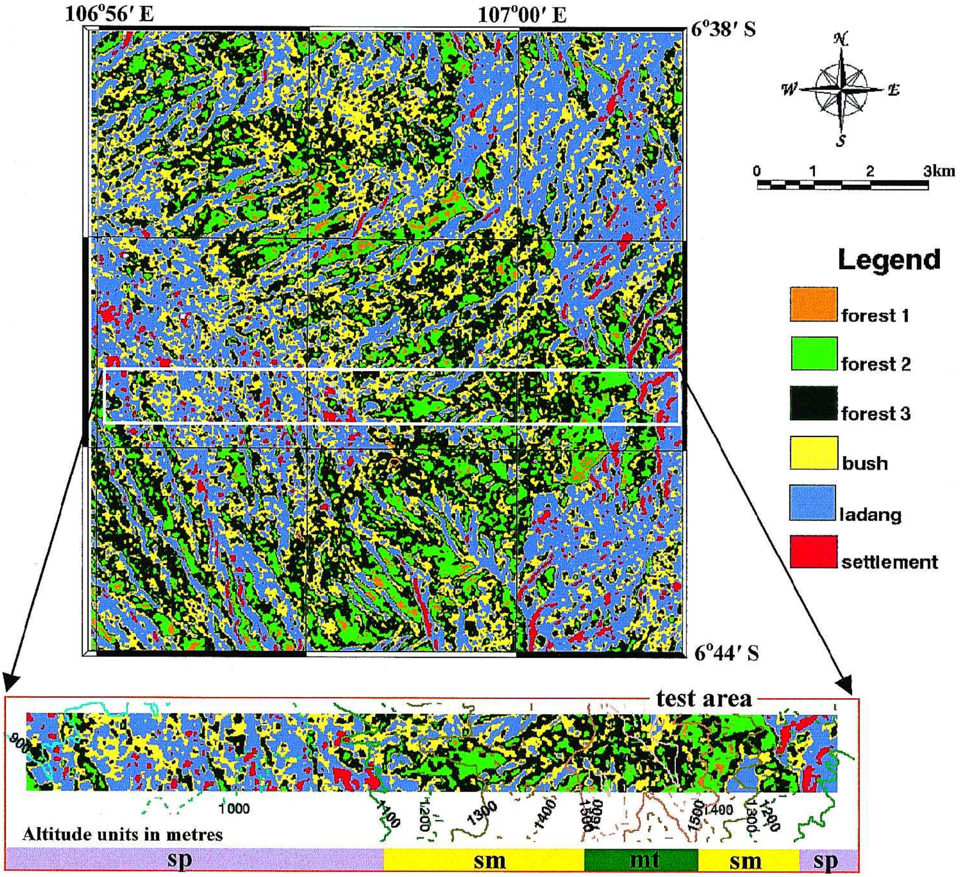

Figure 5. Classification result assigned the distribution of classes in the study area. Test area shows classes distribution in ecosystem zones and its terrain conditions. Ecosystem zones are settlement and paddy (sp), sub-montane (sm) and montane (mt).

Table 2. Relationship between backscattering coefficients and tree trunk diameters of forests in the study area.

Classes	Mean of backscattering coefficient (dB)	Trunk diameter (m)
Forest 1	− 56	0.34
Forest 2	− 53	0.36
Forest 3	− 51	0.37

as seen in table 2, the trunk diameter of each forest class was obtained. This result shows that trees in sub-montane and montane tropical forest zones have a trunk diameter between 0.3 m and 0.4 m. These results matched well with the ground data.

5. Conclusion

The numerical analysis and simulation were conducted to analyse the relationship between the backscattering coefficients and trunk diameters of four species of Java-Indonesian trees. These results succeeded in estimating the trunk diameters of

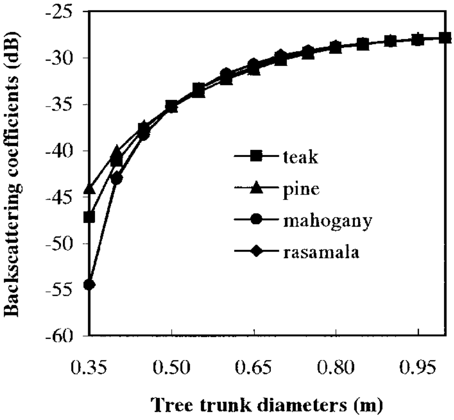

Figure 6. Relationship between the trunk diameters of four species of Java-Indonesian trees and its backscattering coefficients.

rasamala that was widely distributed in the Cisarua tropical forest, west Java, Indonesia. While this study focused on a single site in west Java, Indonesia, it is reasonable to expect that this method or variations could be successful in estimating tree trunk diameters in similar tropical forest regions of the world.

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