RADAR REMOTE SENSING FOR VEGETATION WITH
SPECIAL REFERENCE TO NPAH DELINEATION ON SIR-A
IMAGE

by
J.P. Gastelle-Echegorry

ABSTRACT

Active microwave is a promising tool for monitoring vegetation
and agricultural crops: the biomass, the stage of growth and deviations
from regular plant development due to stress and invasions may be
inferred from radar data. In order to do so, two main steps must be
considered: the changes of the measured radar signals must be
correlated to the backscattering coefficients of the targets, the latter
of which must be defined towards the biomass and structure of the
vegetation. The definition of such relationship is not an easy task due
to the large number of physical parameters which characterize the
target: type of crop and soil, humidity, structure, slope, etc. and the
sensor (wavelength, polarisation, shooting angle). Moreover, these
parameters are interrelated. Two basic models and some experiments,
especially with reference to a successful but unexplained attempt of
NPAH delineation with SIR-A imagery is presented after three main
levels of vegetation observation are defined and the main physical
parameters for the backscattering process are reviewed. Although the
few experiments conducted to date show that imaging radar has the
potential to provide useful information with regard to vegetation no
concrete information exists with regard to optimum angle of incidence,
frequency or polarization configuration.

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ing Centre for Image Interpretation and Integrated Survey), UGM-BAKOSURTANAL, Faculty of
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INTRODUCTION

Due to its all-weather capability, interest in using active microwave remote sensing as a tool for vegetation analysis and monitoring has grown. Numerous experiments have shown the good promise of radar for vegetation. Nowadays, most of vegetation studies with radar are only experimental, users attempt to define and explain the relationship between the backscattered signals and the numerous characteristics of vegetation. Such a signature research is especially important to microwave remote sensing, because a radar image never appears like the familiar optical images. Moreover, mineral properties in the microwave spectrum are also different from those in the visible spectrum. In X-band, for example, Loughi et al. (1984, 1986) showed that the backscattered power decreases in the sequence of rough soil, concrete, grass, and asphalt. Although backscattering was mainly surface process, due to volume scattering, subsurface boundaries were located for concrete. The main steps to an understanding of vegetation backscattering are reviewed as follows: In the definition of the level of observation, (i) the description of the main physical parameters, and (ii) basic modeling. It is followed by a presentation of Npoh delineation with SIR-A imagery. This example illustrates the potential of radar for routine vegetation analysis.

VEGETATION BACKSCATTERING

With an ideally calibrated radar, the backscattered energy $T$ from a target located in $(x,y)$ is:

$$ I = K \cdot \alpha(x,y) $$

where $TK$ depends on the sensor and shooting geometry, and $\alpha(x,y)$ is the backscattering cross-section of the target. For each scatterer of a vegetation canopy, let $Q_{i}$ be the sum of the cross sections for reflection by scattering, and $P_{i}$ the transmitted power from the transmitting antenna that has an antenna gain $G_{i}$. After interacting with the scatterer at range $R$, the amount of power scattered is:

$$ P_{s} = P_{i} \cdot G_{i} \cdot Q_{i} / 4\pi R^{2} $$

One defines the backscattering cross section $\sigma$ to be the value that $Q_{s}$ would have if $P_{s}$ was equally scattered in all directions (isotropic scattering pattern). The distribution of $\sigma_{s}$ about the scatterer can be given by the phase function $p_{s}$, that is a function of the directions of incidence and scattering:

$$ P_{s} = p_{s} P_{i} \text{which means} s = p_{s} Q_{s} $$

For an isotropic scattering, $s$ is unity. Reconsidering the Rayleigh scattering, if the size of the scatterer is smaller than the microwave wavelength, it is found:

$$ p = 0.75 (4\pi \lambda^{2} + 1) $$
where \( \theta \) is the angle between the directions of the incident and scattered rays. For Rayleigh backscattering the "\( g \)" value is 1.5.

In order to determine the physical characteristics of the target we must first correlate these characteristics with the observable sensor "\( s \)". At this stage two main types of question must be answered: what are the significant physical parameters and what is the present level of observation? It can be roughly stated that the significant parameters of a target are its geometric and electrical characteristics, whereas the level of observation depends on the site of the object towards the microwave wavelength. The size of the pixel is always considered large relative to the wavelength. Ulaby (1983) stresses three main levels of observation: (i) sub-scatterer scale: the different electrical characteristics of the different components of the scatterer must be considered; (ii) scatterer scale: the size of the target is about the one of the wavelength. Due to the difficulty to obtain meaningful measurements of the scattering, absorption and emission behavior of an individual scatterer, many scatterers of the same type (shape, orientation, size, etc.) must be considered; (iii) sensor resolution scale: it must be considered the integration of many effects, such as the spatial distribution density, homogeneity, etc. of the set of scatterers must be considered. In a very rough way it can be stated that the geometric characteristics (roughness, orientation, etc.) are quite significant for the spatial distribution of the scattered radiation. On the other hand, the electrical characteristics, which mainly depend on the dielectric properties, are quite significant for the intensity of the integrated scattered radiation.

Some interrelations must be stressed between the previously mentioned target characteristics and the parameters of the incident electromagnetic wave: (i) the smaller the frequency and the smoother the apparent surface, the smaller the standard deviation of the surface height variation and the surface correlation length will be (Boh, 1984; Figure 1); (ii) the real and imaginary parts of the permittivity (Figure 2) vary with the microwave frequency (Bokhsh, 1984); (iii) the bidirectional scattering factors, which depend on the local incidence and reflection angles and on the target permittivity, depend also on the polarization (Figure 3) of the incident electromagnetic wave (Boh, 1984).
Figure 1: Specular Reflection (a) and Diffuse Reflection (b)

Note: (a) Specular Reflection: the incident electromagnetic wave is reflected according to $\theta_i = \theta_r$, $\phi_i = \phi_r$, and $R_r$ and $R_s$ are the reflection coefficients corresponding to the horizontal and vertical components of the wave (Figure 3).

(b) Diffuse Reflection: there is a reflection even if $\theta_i \neq \theta_r$. If we have a gaussian distribution of the irregularities heights the corresponding standard deviation is $\Delta h^2$: then for $\theta_i \neq \theta_r$, we have to introduce an additional reflection coefficient $p^d$:

$$p^d = \exp \left(-\frac{\Delta h^2}{\Delta h^2} \right)$$

For large wavelengths such that $\lambda >> \text{diameter}$, then $p^d \approx 1$ smooth surface. A Surface can seem rough with a normal incidence and smooth with a grazing incidence. The surface correlation length would have to be also considered.

THE MAIN PHYSICAL PARAMETERS

For a microwave radar the vegetation canopy looks like a cloud of volume scatterers composed of a very large number of discrete plane components (leaves, stalks, fruits, etc.) underlain by a soil which may contribute surface scattering. The vegetation backscattering depends a lot on the geometric and electrical properties of vegetation, which are mainly determined by the ones of the water content within vegetation: this being considered a mixture of dry matter and water. Indeed, there is more than 50 percent of water within healthy vegetation, for microwave frequencies (GHz) the water permittivity (11.4 < $\varepsilon_r$) is quite larger than the one of dry matter (2.3 < $\varepsilon_r$), which usually induces larger intensities for reflected signals (Figure 3) and thus for backscattered signals.
Figure 3. (a) Specular Reflection over the Sea.

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vertical polarization.

horizontal polarization.
Figure 3. (Continued).
(b) Specular Reflection over the Sea.

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horizontal polarization.
It appears that the total amount and spatial distribution of water within vegetation are significant parameters that explain the characteristics (intensity, spatial distribution, and polarization) of the scattered signals. Other parameters, such as density, which induces a variability in permittivity (Figure 4), may also be significant. The link between the vegetation water content and the backscatter of signals is very valuable to study vegetation: the total water content is linked with biomass, whereas the spatial distribution of this water is linked to the vegetation growth stage through its morphology and structure. The quantitative description of the vegetation structure is not an easy task: for a backscatter model, stalks may be considered like dielectric cylinders whereas leaves may be considered like individual dielectric scatterers. The type of vegetation structure is very significant for the backscattering process. Indeed, if the electric field $E$ of the incident microwave is parallel to the direction of the fibers of vegetation, the diffusion and absorption of the wave are stronger than if $E$ is perpendicular to the direction of the fibers. Such a statement explains why differently polarized electromagnetic waves lead to different backscattered signals, and why the polarization effect is modulated by the incidence angle (Le Toan et al. 1985).

Note:

(a) $E$ is perpendicular to the direction of the stalks of the rice. In the absence of horizontal leaves, the attenuation coefficient is low and constant with the incidence angle $\theta$.

(b) The angle between the direction of $E$ and the stalk is $\theta_{st}$; thus the attenuation coefficient increases with the incidence angle $\theta$.

In fact, due to its volume scattering effect, the vegetation acts like a depolarizer. Usually, this effect is enhanced with the increase of the incidence angle.

An important indirect parameter which often considered is the penetration depth $d$. It gives an estimate of the medium volume which absorbs the transmit-
Figure 4: The Effect of Salinity on the Water Dielectric Constant of $\varepsilon'$ (a) and $\varepsilon''$ (b). The measured dielectric constants of corn leaves at 1.5, 5 and 8 GHz (c).
It is defined as the depth to which the amplitude of the microwave is divided by "d". Indeed the electromagnetic attenuation is equal to:

\[ \exp \left( -2\pi \frac{d}{\lambda} \right) \]

"d" is the physical depth, "p" the complex part of the square root of the complex permittivity "ε"°, and "λ" the wavelength in vacuum. For an homogeneous medium with \( \varepsilon = \varepsilon ' - j \varepsilon " \), \( ω0 = \varepsilon ' / \varepsilon " \):

\[ d = \left( \frac{2\pi}{\lambda} \right) \frac{1}{\sqrt{\varepsilon ' \cos \delta - \sin \delta \cos \delta}} \]

whereas the wavelength in the homogeneous medium is:

\[ \lambda_m = \frac{\lambda}{\sqrt{\varepsilon ' \cos \delta - \sin \delta \cos \delta}} \]

Penetration depth depends on frequency and on the dielectric properties of the medium. Figure 5 shows it increases with the wavelength and decreases with the

![Graph showing penetration depth of waves in soil](image-url)

**Figure 5:** Penetration depth of waves in the soil: sea water (A), humid soil (B), fresh water (C), rather dry soil (D) and very dry soil (E).
For vegetation, due to its heterogeneous and spatial variations of the dielectric properties must be considered. For soil with an electrical conductivity of $\gamma$, large wavelengths increase $\varepsilon'$ = 60 cm and:

\[ \text{Vs (soil)} = \sqrt{\frac{30}{\gamma}} \quad \text{and} \quad \text{Vs (soil)} = \sqrt{\frac{1}{30\gamma/2\pi}} \]

With large wavelengths the parameter $\varepsilon'$ has no more influence and all media tend to act like conductors (Bonifay, 1984).

Two models and some experiments are reviewed below in order to illustrate the influence of the previously defined parameters on vegetation backscattering.

BACKSCATTER MODELS AND EXPERIMENTS

Cloud Model

Microwave backscattering of vegetation, and its scattering underlying surface was presented by Attema and Ubers (1978) as a result of the scattering and attenuation by a uniform cloud of identical spherical scattering elements similar to that by a cloud of water droplets, where multiple scattering effects were neglected. Such an approach constitutes afirsts model for vegetation study with radar, that is "Cloud Model". Scattering elements are supposed to have a density "N" (m$^{-3}$), a backscattering cross section "s^2", and a total attenuation cross section "Q" (m$^{-2}$). Then, the backscattering coefficient of the combined combined canopy and soil $\sigma^0$ (m$^{-2}$ Sr$^{-1}$) is:

\[ \sigma^0 = \left( \text{p} \cdot \text{cos}^2(\theta) \right) \left( 1 - \frac{\lambda}{\lambda_0} \right) + \sigma_t^2 \]

with $L = \exp(-ah \text{ sec} \theta)$

where "L" is the one-way transmittance of vegetation canopy along the slant path (inclined at the sensor look angle $\theta$); "h" is the canopy physical vertical thickness, "N" (m$^{-3}$ m$^{-2}$), the sum of the backscattering cross-section area in a unit volume, is equal to "N" ($\sigma^2$) + "Q" (m$^{-2}$ m$^{-3}$), volume extinction (scattering and absorption) coefficient, which measures the sum of the extinction cross-sectional areas in a unit volume, is equal to "N" - "Q", and "$\sigma_t$" is the backscattering coefficient of the mill surface underlying the vegetation. By considering the mean density of scattering elements "N" and "Q", instead of "N" - "Q", the equations which represent the basic cloud model are:

\[ \sigma^0 = \left( \text{p} \cdot \text{cos}^2(\theta) \right) \left( 1 - \frac{\lambda}{\lambda_0} \right) + \left( \text{N} - \text{Q} \right) \cdot L \]

with $L = \exp(-ah \text{ sec} \theta)$
It must be stressed that three canopy parameters \( a, Q, h \), one soil parameter \( \sigma_x \) and one explicit sensor parameter \( B \) determine the backscattering coefficient \( \sigma^b \). When the number of scatterers becomes large, \( L_i \) approaches to zero and \( a/o \) approaches to a constant:

\[
\sigma^b \rightarrow a \cdot \cos 8 \cdot 2Q
\]

As it often occurs with pioneer models some assumptions of the cloud model appear to be too restrictive, which may induce relations such as \( R = N_o a \) and \( N = N Q \) to be no more valid. These hypothesis are: (i) the similarity of all scatterers, (ii) the independance between volume extinction and polarization, (iii) the use of the form \( L_i \) is valid only with like polarization combinations, which means with spherical elements. Thus \( L_i L_j \) would be replaced by \( L_i L_j \), with \( i \) and \( j \) equal to \( M \) or \( V \), (iii) the multiple scattering. (ix) the uniform distribution of the scatterers: leaves can be concentrated in one part of the canopy.

In order to link \( \sigma^b \) with the characteristics of the vegetation, one possibility consists of considering the water content (biomass) and distribution (structure) within vegetation; dry plant matter would also be considered. Olaeby et al. (1984) assumed \( \sigma^b \) and \( \sigma^o \) to be proportional to the water mass within each scatterer. Such an assumption is true for clouds in the Rayleigh domain where the spherical particles are much smaller than the wavelength of the microwaves (Kerker 1990). It is not so true for larger scatterers (Max Domain) of which various sizes, shapes and orientations must be considered through their means and standard deviations. Thus it appears that for vegetation, the size of the scatterer is an important parameter which modulates the effects of volumetric moisture alone.

**REGRESSION MODEL**

Another approach of vegetation backscattering is provided by Eom (1966) and Eom and Fung (1984, 1986). They estimate backscatter with a regression based on radiative transfer models. A vegetative canopy is modeled as a Rayleigh scattering layer above an irregular Kirchoff surface (soil). It was shown that like polarized radar backscattering coefficient \( \sigma^b \) consists of three components: a volume component \( \sigma^v \), a surface or ground component \( \sigma^s \), and an interaction or multiple scattering component \( \sigma^m \):

\[
\sigma^b = \sigma^v + \sigma^s + \sigma^m
\]

The Rayleigh first order scattering model results:

\[
\sigma^v = 0.75 \mu \text{w.} \ (1 - \exp (-2\pi/\mu))
\]
where \( \alpha = \cos \theta \), \( \theta \) being the incidence angle, \( \psi = \psi_{1}(\psi_{2} + \psi_{3}) \) and \( \psi = \psi_{1}(\psi_{2} + \psi_{3}) \) being scattering coefficient, absorption coefficient, and physical depth of layer respectively. A numerical study permitted from and Fung to get:

\[
\alpha = 0.672 \mu_{w} (1 + 0.769 \psi_{1} - 0.176 \psi_{2} (1 - \exp(-2.9t/\mu_{w})
\]

The attenuated backscattering coefficient from a Kittelhoff random surface of Gaussian height distribution and exponential correlation function of the surface height (Beckman and Spliethoff, 1963; Bass and Fulfes, 1979) is:

\[
\alpha_{t} = \left[ \sum_{n} \frac{Z(t) \exp(-2t/2Z_{0})}{2Z_{0} \exp(-2t/2Z_{0})} \right]^{2} - \frac{N_{0t}}{t} \exp(-2t/\mu_{w})
\]

where \( Z(t) \) is the Fresnel electric reflection coefficient of the polarization, \( Z_{0} \) is equal to \( 20W/L \), \( Z_{0} \) is the standard deviation of surface height and \( L \) is the correlation length in most practical cases the previous series converges quickly. Assuming that the dominant interaction mechanisms are diffusive scattering by Rayleigh particles from the top of canopy to the ground, a reflection by the underlying perfect planar ground, and a direct attenuation from the ground to the top of canopy, the interaction term takes the following form:

\[
\alpha_{t} = 2\sigma \cdot R_{1} \exp(-r/\mu_{w})
\]

The two types of models previously presented allow to estimate backscattering from vegetated terrain and this lead to an improvement of the theory. It must be stressed that at this time there is no operational model for vegetation backscattering of microwaves with a wavelength of the order of magnitude of the leaves, around 3 cm (Lu, Tong et al., 1963). In the following last some experiments are presented for the purpose of illustrating the effects of vegetation backscattering of sensor frequencies: Reflector antenna, polarization and vegetation parameters (growth stage, leaf orientation, etc.). Moreover, by ascertaining the most influential factors, such as determining of the main sources of scattering, these experiments allow to simplify the theory of backscatter from vegetation.

**EXPERIMENTS**

An attempt to determine the source of backscatter from crops was made by measuring the backscatter for a small area of the crop and then removing the top layer and repeating the measurement (Ibaby et al., 1965; Wu et al., 1964, 1965). In the X-band range it was found that the strongest returns show nearly isotropic backscattering properties and are due to the top leaves for corn, and to
the hills for mld. The attenuation "L" increases with the incidence angle. Figure 6 illustrates the variations of "L" with the slant path which means with the canopy height (Le Toan et al., 1983; Ulaby, 1983). For slant view (head declined) there is a gentle decrease of the transmitted power with the increase of the slant path. The appearance of ears (Wheat heads, etc.) leads to large spatial fluctuations due to the spatial inhomogeneity of the ears. These fluctuations can be no more observable when the size of the pixel induces an integration and thus an homogenization of the discrete signals. Such a statement, verified with crops, may be no more true with forests for which the size of the transect and pixels may have the same order of magnitude. It must be stressed that an increase of the slant path with an increase of the incidence angle may induce an alignment of leaves with the incident beam, which means stronger returns. Microwave attenuation by vegetation varies during the season (Figure 7), mainly because of surface changes of the vegetation, covered biomass, and canopy height. However, all modifications of geometric and electric characteristics of vegetation must be considered; for example, the appearance of large leaves leads to an angle dependence on vegetation volume scattering.

In order to take into account the non-uniform distribution of the scatterers (Hooker et al., 1982) within vegetation, Attema (1983) proposed two-layer model (Figure 8); the total backscattering is supposed to be the sum of backscattering from the soil and the upper and lower layers of the vegetation. The relative backscattering contributions of the soil and vegetation vary during the season. It must be noted that the absolute and relative contributions of the soil and vegetation depend a lot on the frequencies. Figure 9 illustrates the fact that for vegetation-covered terrain the backscattered signal does not depend directly on the soil moisture if 1 - 3 cm, whereas there is a correlation if 1 - 6 cm. Nevertheless as it has been stressed by Subijan (1983), information from the soil may be preserved even with a vegetation penetration depth equal to zero. For instance, the volume and surface characteristics of a dense forest are well correlated with those of the underlying soil and relief changes are specially significant. In general, experiments performed with crops show that, for low frequencies (1.5 and 3 GHz), the radar backscattering of a vegetation-covered area is greatly due to the soil. The influence of this last factor decreases with the increase of the frequency and of the incidence angle. On the other hand, observations made with SENTROR/Surface Imaging Radar (head L) over flooded regions with loose vegetation cover, displayed important backscattering (Eigheta and Elachi, 1982) in this case, the interaction seemed to be due to vegetation and appeared similar to the one of an electromagnetic wave with a randomly rough surface.

Similar to what is performed for visible and infra-red digital data, automatic classifications of microwave data were performed. As previously mentioned, vegetation backscattering and thus vegetation classification depend largely on the relative values of "size of target-wavelength", main direction of the target polarization.
Figure 6: (a) Measured attenuation coefficient of wheat stalks as a function of depth from the top of the canopy (10.2 GHz, VV; 60°, 63% of moisture).
(b) Attenuation of the wave according to the polarization; β varies from 0° to 90° (9 GHz; 90°); measurements performed with wheat.

Figure 7: Computed Canopy Loss (L) for Wheat, Soybeans and Corn over the Entire Growing Season, (5.1 GHz; HH; 10°).
Figure 8: (a) Scattering coefficient $S_{\theta}$ for barley at 50 and 15 degrees incidence angle. Contribution by soil (A), bottom layer (B) and upper layer (C); the crosses (X) display the data from the measurements. (b) The corresponding angular responses at 2 dates.

Figure 9: Simulated Performance of Spaceborne Radar at 10° Incidence Angle for Soil Moisture Determination of Vegetation Covered Terrain at 3 cm Wavelength (a) and at 6 cm Wavelength (b).
end, or incidence angle. Thus, the use of multi-frequency, multi-polarization or multi-incidence angle approaches may be very valuable for vegetation classification. Such an example is provided by a study by Bejnim et al. (1983). The use of bands X and C led to a good separation of the classes “wet,” “forest cover,” and “agricultural land.” However, some confusions could not be avoided, i.e. the classes “forest” and “clover” were mixed, etc. Due to the lack of spatial homogeneity variance of the backscattered signals, the use of the variations of the texture did not improve the classification. Hoveman (1994) showed the utility of X-band in the classification of Dutch forests. He found some empirical relations between the backscattering coefficients and the age of the trees, the crown structure and the total leaf mass. Moreover, texture appeared to be an important discriminating tool for forests. An example of the use of polarimetry for vegetation analysis is provided by spol et al. (1991). An horizontal polarization (1.2 GHz) allowed them to determine a correlation between the height of maritime pine trees and their respective backscattered signals. It is caused by the vertical structure of the trees. An example of radar imagery application for tropical vegetation is presented below.

**OBSERVATION OF NIPAH PALMS WITH SIR—A**

**General Aspects**

The study area is located in East Kalimantan (Indonesia) in the deltaic area of the Berau River (2° 16' N and 117° 50' E). It is characterized by the presence of Nipah with the help of microwave data. Indeed, Nipah fruitcakes are one of the most common, widely distributed, and useful palms of the mangrove forest. It provides valuable products to traditional people living inside mangrove areas: moreover some large-scale commercial interest has developed: its sugar yield is favorable to the cane industry.

**Procedure**

The study was performed with the help of panchromatic aerial photographs (from October 1981: 1 : 1000 000 scale) and of SIR—A images (Band 1 from November 1981: 1 : 250 000 scale). Moreover an aerial survey was conducted by the year 1984. The main comparative results of the photo-interpretation of the radar image (figure 10) and of the aerial photographs are summed up in Table 1 and figure 11.

**Main Conclusions**

The analysis of the SIR—A images lead to the following conclusions:

1. FL is located on a clastic terrain, F2 on a mixed terrain (Salomons, 1985) and the
or mangrove forests on an alluvial terrain.
3. The cultivation areas cannot be determined from the forests F which border them.
4. A "coastal effect" induces the presence of very narrow coastal strips due to the coasts facing in the direction of the radar.
5. The presence of a very bright headland on the radar imagery may be due to a very important flooding of this, maybe newly created, area (Engelhs and Elachi, 1982).

In general, the aerial photographs permitted to better differentiation of the various types of vegetation (12 classes) than the radar imagery (7 classes): this difference is mainly due to the different scales and types of information (passive panchromatic and active band L) of the images considered. However, an important

<table>
<thead>
<tr>
<th>Type of Vegetation</th>
<th>Panchromatic Photography</th>
<th>Radar</th>
<th>C1-C2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest foil C2</td>
<td>No relief. Strongest variation of the tree heights and of the grey tones in larger areas.</td>
<td>Road-pediment. VG2.</td>
<td>C1-C2</td>
</tr>
<tr>
<td>Low-land E3</td>
<td>No relief. Stronger variation of the tree heights and of the grey tones in larger areas.</td>
<td>No identifiable.</td>
<td>C1-C2</td>
</tr>
<tr>
<td>Forest (F1)</td>
<td>Mosses of geomorphological shapes with homogenous grey values. No C1 and C2 values.</td>
<td>No identifiable.</td>
<td>C1-C2</td>
</tr>
<tr>
<td>Mountainous G1</td>
<td>Small density values. Darker.</td>
<td>Very low pediments.</td>
<td>C1-C2</td>
</tr>
<tr>
<td>Mountainous G2</td>
<td>Grey values higher than for G1. No G1 values.</td>
<td>Dark and grey.</td>
<td>C1-C2</td>
</tr>
<tr>
<td>Mountainous G3</td>
<td>Grey values higher than for G2.</td>
<td>No identifiable.</td>
<td>C1-C2</td>
</tr>
<tr>
<td>Plain (F2)</td>
<td>No grey values. Mesogrey dark grey values. Tree coverage and similar grey values. Homogenous.</td>
<td>Grey values.</td>
<td>C1-C2</td>
</tr>
<tr>
<td>Plain (F2)</td>
<td>Very low pediment.</td>
<td>Very low pediment.</td>
<td>C1-C2</td>
</tr>
<tr>
<td>Coastal (F3)</td>
<td>No granular, uniform, strong, marshy texture. Low vegetation.</td>
<td>No identifiable.</td>
<td>C1-C2</td>
</tr>
</tbody>
</table>

Note: VG1 = very good identification and C1 = good identification.
Conclusion of this study is the very good discrimination of the Nipah fruticosa on the SAR—A imagery, quite more easily than with the considered panshadowsatic photographs. Thus, radar imagery (band L), even at a large scale, appears to be a good tool to locate this type of vegetation.

CONCLUSION

The few experiments conducted to date show that imaging radar has the potential to provide useful information with regard to vegetation. For example, the rapid rise in the full-canopy backscattering coefficient in the early part of the season shows the extreme sensitivity of backscattering to early changes in green leaf area index. Moreover, microwave response may be more sensitive to events, such as the transplantation of photosynthetic processes from green leaves to fruits in the reproduction process than green leaf area index, a parameter that controls the visible and infrared vegetation properties. It is through these geometric and electrical characteristics that vegetation stands and structure can be analyzed on an experimental basis. Water content and distribution within vegetation are determining parameters. However, other factors, such as the size and orientation of the individual scatterers, must be considered in order to improve the vegetation backscatter models, and thus to allow vegetation analysis on an operational basis. It must be stressed that at this time no concrete information exists with regard to optimum angle of incidence, frequency or polarization configuration. Due to the important variety of vegetation parameters, such as the canopy density, the presence of vertical stalks, the water content, etc., a multiple microwave configuration will often be necessary for a good vegetation classification. For example, the study presented here points out that SAR—A configuration is very efficient for Nipah palm delineation but not for the other landscape units.

ACKNOWLEDGMENT

Gratitude is addressed to Mr. Dukuhiri who performed field check for the study about Nipah delineation. He is a staff member in Remote Sensing at the Faculty of Geography, Gadjah Mada university, Yogyakarta, Indonesia.

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(11):2070-84.


