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

by
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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 investation 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, polarization, shooting angle). Moreover, these parameters are interrelated. Two basic models and some experiments, especially with reference to a successful but unexplained attempt of Nipah 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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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 relationships 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, material properties in the microwave spectrum are also different from those in the visible spectrum. In X-band, for example, Zoughi *et al.* (1984;1986) showed that the backscattered power decreases in the sequence of rough soil, concrete, grass, and asphalt. Although backscattering was mainly a 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: (i) the definition of the level of observation, (ii) the description of the main physical parameters, and (iii) basic modeling. It is followed by a presentation of *Nipah* 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 "I" from a target located in (x, y) is:

$$I = K.\ \sigma(x,y)$$

where "K" depends on the sensor and shooting geometry, and "σ" ($m^2 m^2$) is the backscattering cross-section of the target. For each scatterer of a vegetation canopy, let "Qs" (m^2) be the sum of the cross sections for extinction by scattering, and "Pt" the transmitted power from the transmitting antenna that has an antenna gain "Gt". After interacting with the scatterer at range "R" the amount of power scattered is :

$$Ps = Pt.Gt.Qs\ /\ 4\pi R^2$$

One defines the backscattering cross section "σ" to be the value that "Qs" would have if "Ps" was equally scattered in all directions (isotropic scattering pattern). The distribution of "Ps" about the scatterer can be given by the phase function "p", that is a function of the directions of incidence and scattering.

$$I = p.Ps \text{ which means } \sigma = p.Qs.$$

For an isotropic scattering, "p" is unity. By considering the Rayleigh scattering, if the size of the scatterer is smaller than the microwave wavelength, it is found :

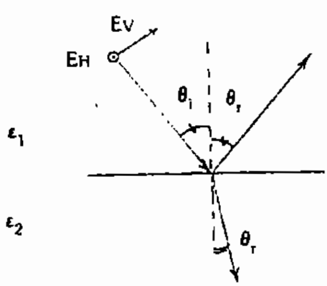
$$p = 0.75\ (\cos^2\theta + 1)$$

where θ is the angle between the directions of the incident and scattered rays. For Rayleigh backscattering the "p" value is 1.5.

In order to determine the physical characteristics of the target we must first correlate these characteristics with the observable sensor "σ". 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 sifnificant parameters of a target are its geometric and electical characteristics, whereas the level of observation depends on the size of the object towards the microwave wavelength. The size of the pixels 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 (Boithias. 1984; Figure 1), (ii) the real and imaginary parts of the permittivity (Figure 2) vary with the microwave frequency (Boithias, 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 (Boithias, 1984).

(a)



$$R_H = \frac{\cos\theta - \sqrt{\varepsilon - \sin^2\theta}}{\cos\theta + \sqrt{\varepsilon - \sin^2\theta}}$$

$$R_V = \frac{\cos\theta - \sqrt{\varepsilon - \sin^2\theta/\varepsilon}}{\cos\theta + \sqrt{\varepsilon - \sin^2\theta/\varepsilon}}$$

$$\varepsilon = n_2/n_1 = \varepsilon_2/\varepsilon_1$$

$$\mathrm{tg}\,\theta_i = n_2/n_1 = R_v = 0$$

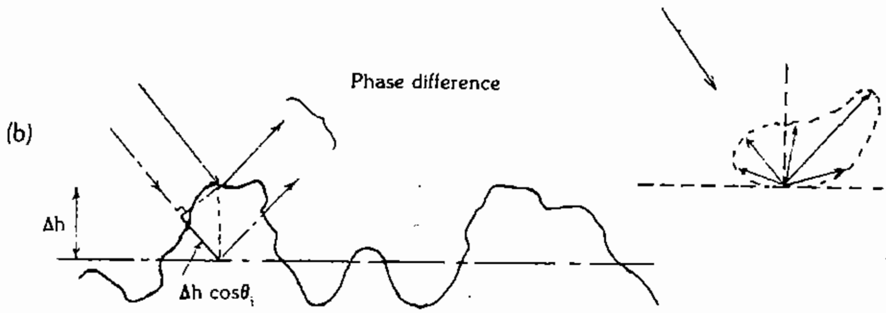


Figure 1: Specular Reflection (a) and Diffuse Reflection (b)

Note:
(a) Specular Reflection: the incident electromagnetic wave is reflected according $\theta_r = \theta_i$: Rh and Rv are the reflection coefficients corresponding to the horizontal and vertical components of the wave (Figure 3).
(b) Diffuse Reflection; there is a reflection energy even if $\theta_r \neq \theta_i$. If we have a gaussian distribution of the irregularities heights the corresponding standard deviation is "Δh"; then for $\theta_r \cong \theta_i$ we have to introduce an additional reflection coefficient "ϱ".

$$\varrho = \exp\left[-8\pi^2 (\Delta h.\cos\theta_i/\lambda)^2\right]$$

For large wavelengthe such that $\lambda \gg \Delta h\cos\theta_i$, then $\varrho \cong 1$ (smooth surface). A Surface can seem rough with a normal incidence and smooth with a grazing incidence. The surface correlation lenght 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 plant 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 ($\|\varepsilon\|$ # 80) is quite larger than the one of dry matter ($\|\varepsilon\|$ # 3). which usually induces larger intensities for reflected signals (Figure 3) and thus for backscattered signals.

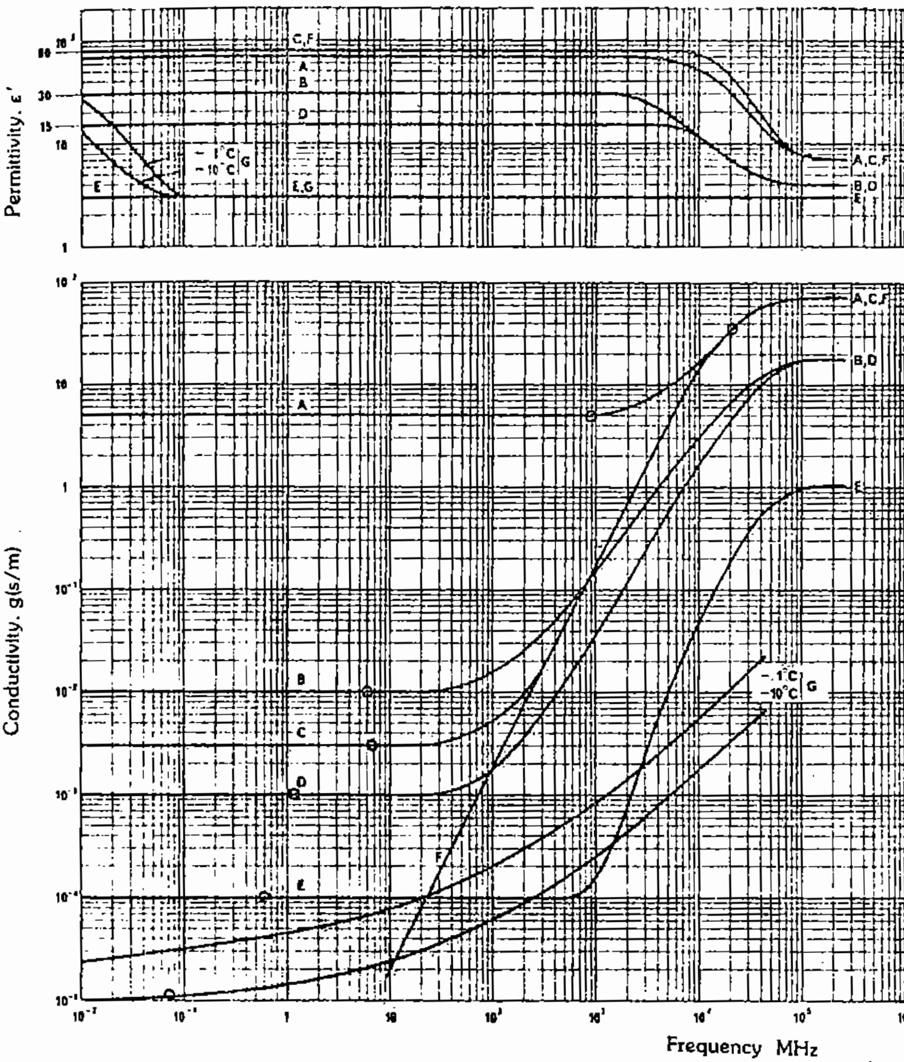


Figure 2: Variation of the Dielectric Constant "ε" with the Frequency, for Different Targets.

Note:

Sea water (A), humid soil (B), fresh water (C), rather dry soil (D), very dry soil (E), pure water (F) and ice (G). We have: $\varepsilon = \varepsilon' - j\varepsilon''$; the loss factor "$\varepsilon''$" is proportional to the electrical conductivity "g" and to the wavelength (for soil: $\varepsilon = \varepsilon' - j60g\lambda$):

(a) Variations of ε'

(b) Variations of g

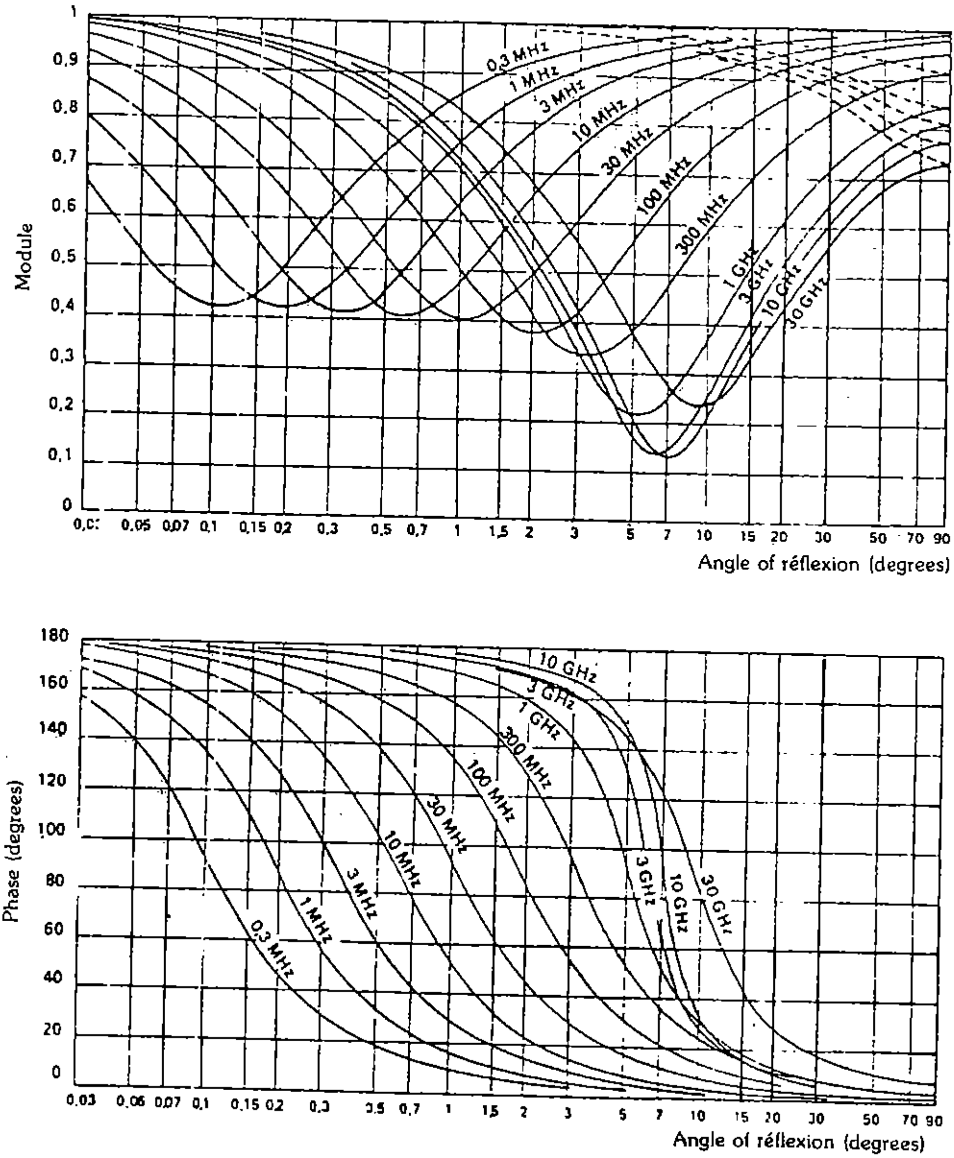


Figure 3. (a) Specular Reflection over the Sea.

__________ vertical polarisation.

-------------- horizontal polarisation.

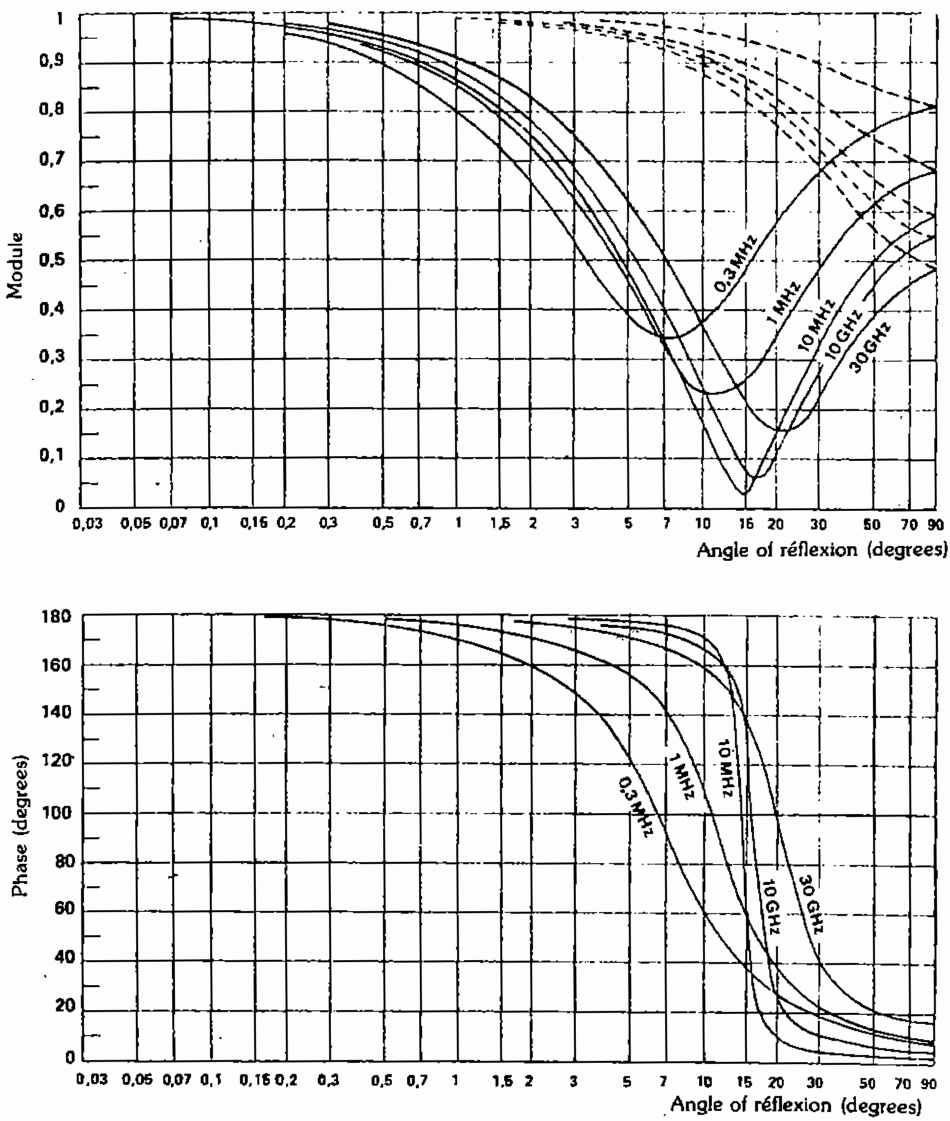


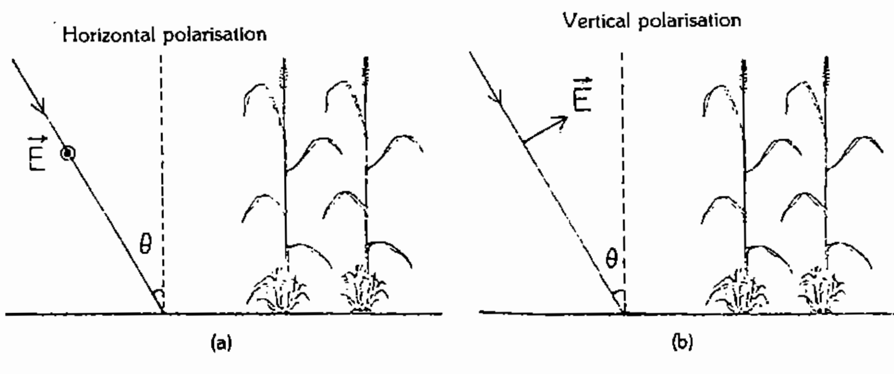
Figure 3. (Continued).

(b) Specular Reflection over the Sea.

———————— vertical polarisation.

-------------- horizontal polarisation.

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 salinity which induces a variability of permittivity (Figure 4). may also be significant. The link between the vegetation water content and the backscattered 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.* 1983).



Note:

(a) "E" is perpendicular to the direction of the stalks: thus. in the absence of horizontal leaves. the attenuation coefficient is low and constant with the incidence angle "θ".

(b) The angle between the direction of "E" and the stalks is "π-θ"; thus the attenuation coefficient increases with the incidence angle "θ".

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-

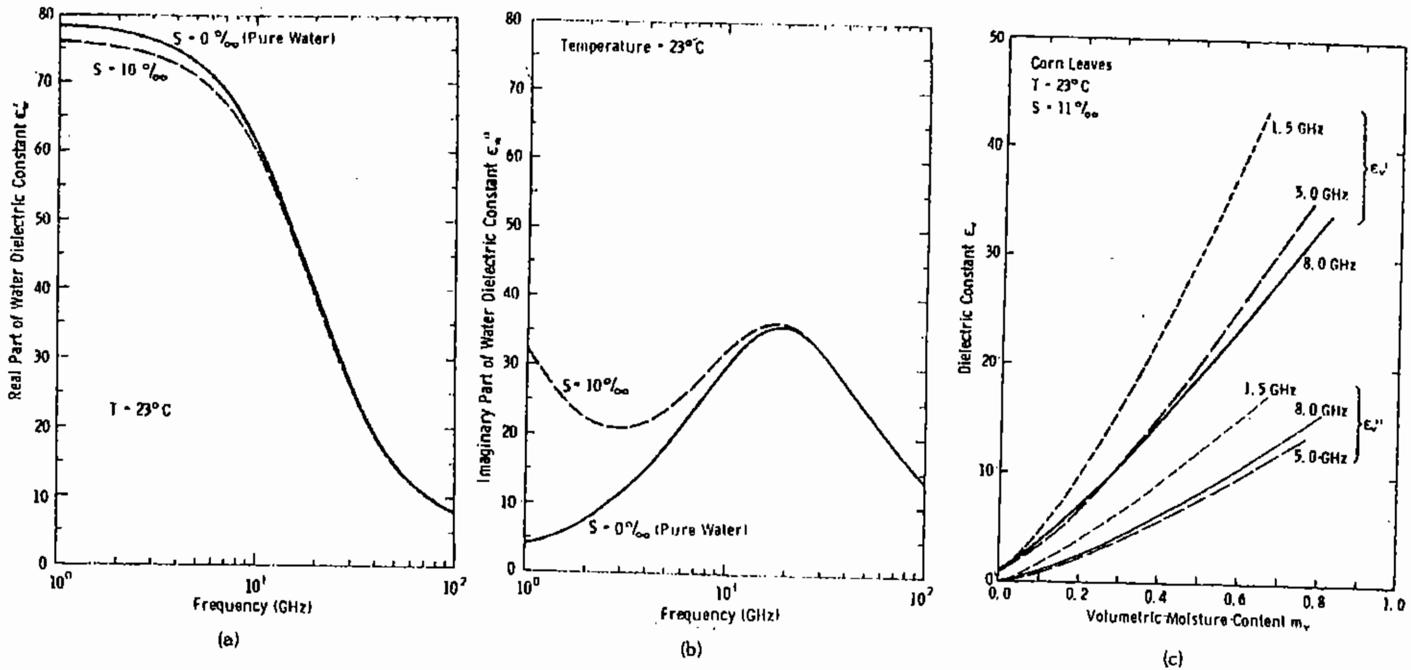


Figure 4: The Effect of Salinity on the Water Dielectric Constant of ε′ (a) and ε″ (b). The measured dielectric constants of corn leaves at 1.5, 5 and 8 GHz (c).

ted energy. It is defined as the depth to which the amplitude of the microwave is divided by "d". Indeed the electromagnetic attenuation is equal to:

$$\exp(-2\pi p.z/\lambda)$$

"z" is the physical depth, "p" the complex part of the square root of the complex permitivity "c", and "λ" the wavelength in vacuum. For an homogeneous medium with ($\varepsilon = \varepsilon' - j.\varepsilon''$; tg& $= \varepsilon''/\varepsilon'$):

$$d = (\lambda/2\pi)/[\sqrt{\varepsilon/\cos\&} \cdot \sin(\&/2)]$$

whereas the wavelength in the homogeneous medium is:

$$\lambda m = \lambda / [\sqrt{\varepsilon/\cos\&} \cdot \cos(\&/2)]$$

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

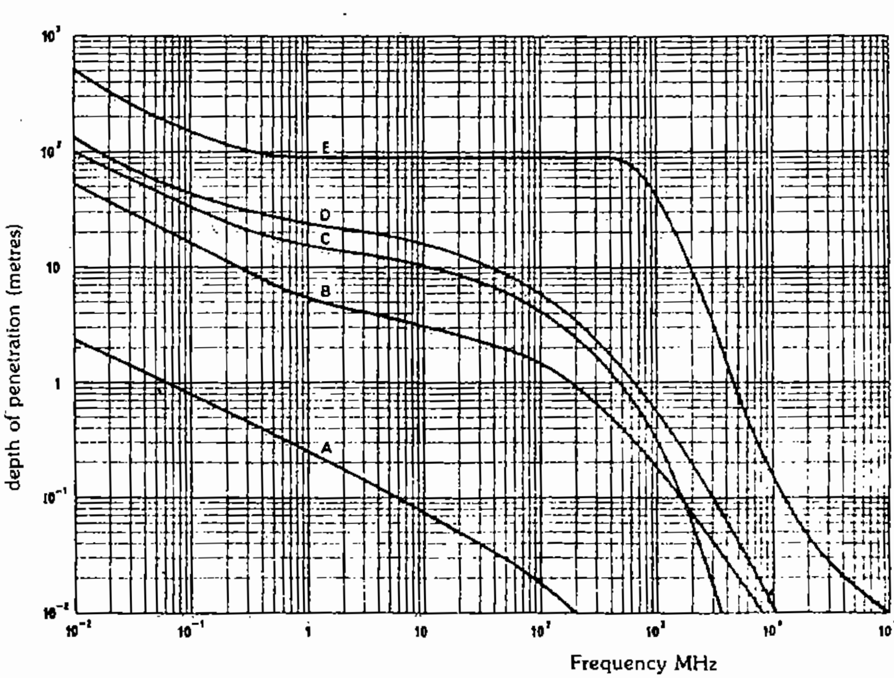


Figure 5: Penetration depth of waves in the soil: sea water (A), humid soil (B), fresh water (C), rather dry soil (D) and very dry soil (E).

moisture. For vegetation, due to its heterogeneous cover, spatial variations of the dielectric properties must be considered. For soil with an electrical conductivity "g", larger wavelengths increase $\varepsilon'' = 60g.\lambda$ and:

$$\lambda m \text{ (soil)} \rightarrow \sqrt{\lambda/30g} \quad \text{and} \quad d\text{(soil)} \rightarrow \sqrt{\lambda/30g}/2\pi$$

With large wavelengths the parameter 'ε'' has no more influence and all media tend to act like conductors (Boithias, 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 Ulaby (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 a pioneer 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 "σ", and a total attenuation cross section "Q" (m^2). Then, the backscattering coefficient of the combined combined canopy and soil, σ° ($m^2\ m^{-2}$) is:

$$\sigma^\circ = (n.\cos\theta/2\alpha)\ .\ (1-L^2) + \sigma^\circ_s.L^2$$
$$\text{with } L = \exp(-\alpha h \sec\theta)$$

where "L" is the one-way transmittance of vegetation canopy along the slant path (inclined at the sensor look angle θ); "h" is the canopy physical vertical thickness; "n" ($m^2\ m^3$), the sum of the backscattering cross-section areas in a unit volume, is equal to "$N.\sigma$"; "α" ($m^2\ m^3$), volume extinction (scattering and absorption) coefficient which means the sum of the extinction cross-sectional areas in a unit volume, is equal to "N.Q"; and "σ°_s is the backscattering coefficient of the soil surtace underlying the vegetation. By considering the areal density of scatterers elements "Na", equal to "N.h", the equations which represent the basic cloud model are:

$$\sigma^\circ = (\sigma \cos\theta/2Q).(1 - L^2) + \sigma^\circ_s\ .\ L^2$$
$$\text{with} \quad L = \exp(- Na.Q.\sec\theta)$$

It must be stressed that three canopy parameters "σ, Q, h", one soil parameter "σ_s^o" and one explicit sensor parameter "θ" determine the backscattering coefficient "σ". When the number of scatterers becomes large "L" approaches to zero and "σ" approaches to a constant:

$$\sigma^o \rightarrow \sigma \,.\, \cos\theta/2Q$$

As it often occurs with pioneer models some assumptions of the cloud model appear to be too restrictive, which may induce relations such as "n = N.σ" and "α = N.Q" to be no more valid. These hypothesis are: (i) the similarity of all scatterers the size, orientation and shape are not the same; moreover they change during the season, (ii) the independance between volume extinction and polarization: the use of the form "L" is valid only with like polarization combinations, which means with spherical elements. Thus "L^2" would be replaced by "Li.Lj", with i and j equal to H or V, (iii) the multiple scattering, (iv) the uniform distribution of the scatterers: leaves can be concentrated in one part of the canopy.

In order to link "σ" 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. Ulaby *et al* (1984) assumed "Q" and "σ" 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 (Kerr, 1952). It is no more true for larger scatterers (Mie 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 scatterers is an important parameter which modulates the effects of volumetric moisture alone.

REGRESSION MODEL

Another approach of vegetation backscattering is provided by Eom (1986) 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 Kirchhoff surface (soil). It was shown that like polarized radar backscattering coefficient "σ" consists of three components: a volume component "σ^o", a surface or ground component "σ_s^o, and an interaction or multiple scattering component "σ_s^o":

$$\sigma^o = \sigma_v^o + \sigma_s^o + \sigma_1^o$$

The Rayleigh first order scattering model results:

$$\sigma_v^o = 0.75\,\mu.w.\,(1 - \exp(-2\tau/\mu))$$

where "$\mu = \cos\theta$", "θ" being the incidence angle, "$w = Ks/(Ks + Ka)$" and "$r = (Ka + Ks).h$", "Ks", "Ka" and "h" being scattering coefficient, absorption coefficient, and physical depth of layer respectively. A numerical study permitted Eom and Fung to get:

$$\sigma^\circ = 0.672\,\mu.w.\,(1 + 0.769\,wr - 0.176\,wr).(1-\exp(-2.9r/\mu))$$

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

$$\sigma_s^\circ = \left[\sum_{n=1}^{\infty} \frac{2R^2.u^2.\exp(-4k^2.Z^2.u^2).(4k^2.Z^2.u^2).(k^2.n/L)}{n!\,(4k^2.\sin^2\theta + n2/L^2)^{15}} \right] \exp(-2r/u)$$

where "R" is the Fresnel electric reflection coefficient of like polarization, "k" is equal to "$2\pi/L$", "Z" is the standard deviation of surface hight and "L" is the correlation length in most practical cases the previous series converges quickly.

Assuming that the dominant interaction mechanisms are a diffuse 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 :

$$\sigma_s^\circ = 2\sigma_v^\circ.\,R^2.\exp(-r/\mu)$$

The two types of models previously presented allow experimenter to approximately estimate backscattering from vegetated terrain and thus 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 (Le Toan *et al.*, 1983). In the following part some experiments are presented for the purpose of illustrating the effects on vegetation backscattering of sensor (frequency, shooting angle, 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 layers and repeating the measurement (Ulaby *et al.*, 1982; Wu *et al.*, 1984, 1985). 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 heads for milo. The attenuation "L" increased 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 stalk wheat (head decapited) 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 fluctuation can be no more observable when the size of the pixel induces an integration and thus an homogeneization of the discrete signals. Such a statement, verified with crops, may be no more true with forests for which the sizes of the trees 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 indicent 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 (Hoekman *et al.*, 1982) within vegetation, Attema (1983) proposed two layer model (Figure8): 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 Sabins (1983), information from the soil may be present 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 incident angle. On the other hand, observations made with Seasat Spaceborne Imaging Radar (band L) over flooded regions with heavy vegetation cover, displayed important backscattering (Engheta 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 are 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

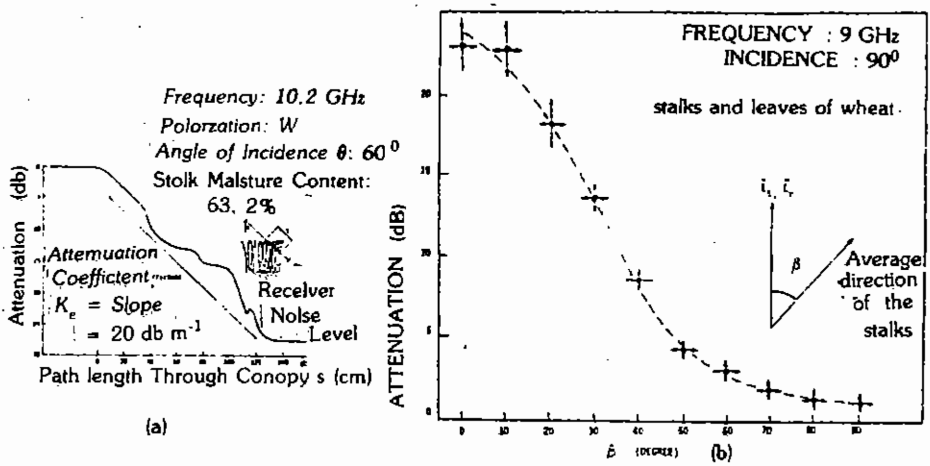


Figure 6: (a) *Measured attenuation coefficient of wheat stalks as a function of depth from the top of the canopy (10.2 GHz; VV; 60°; 63% of moisture).*

(b) *Attenuation of the wave according to the polarization: β varies from 0° to 90° (9 GHz; 90°); measurements performed with wheat.*

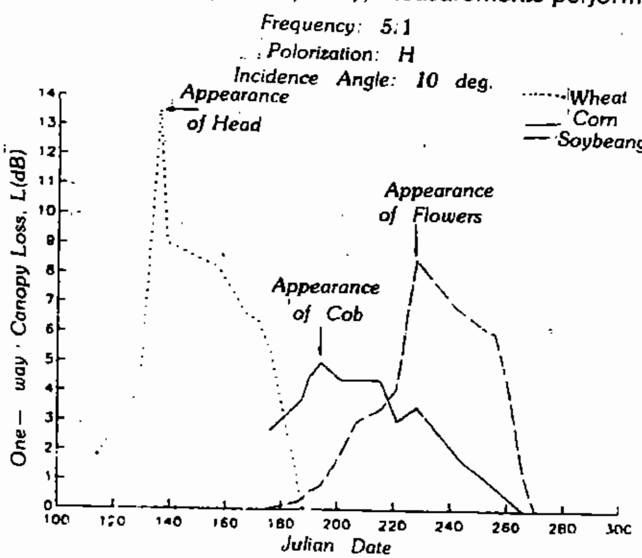


Figure 7: *Computed Canopy Loss (L) for Wheat, Soybeans and Corn over the Entire Growing Season; (5.1 GHz; HH; 10°).*

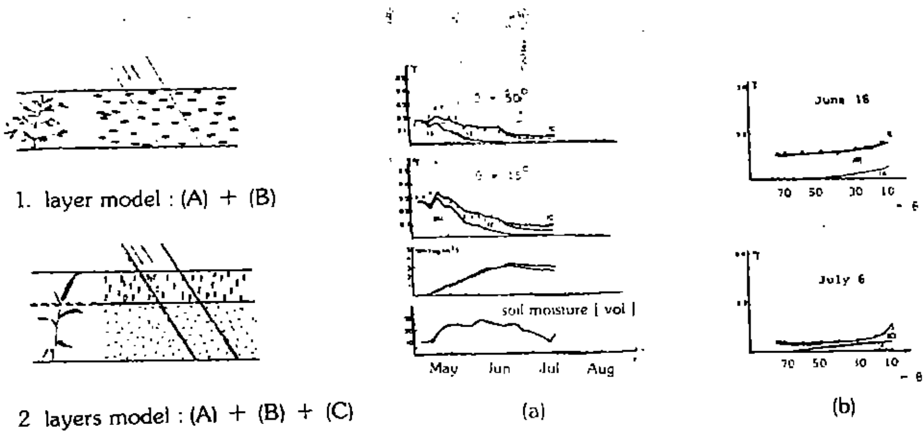


Figure 8: (a) Scattering coefficient "6_o" for barley at 50 and 15 degrees incidence angle. Contribution by soil (A), bottom layer (B) and upper layer (C); the crosses (X) display the data from the measurements.
(b) The corresponding angular responses at 2 dates.

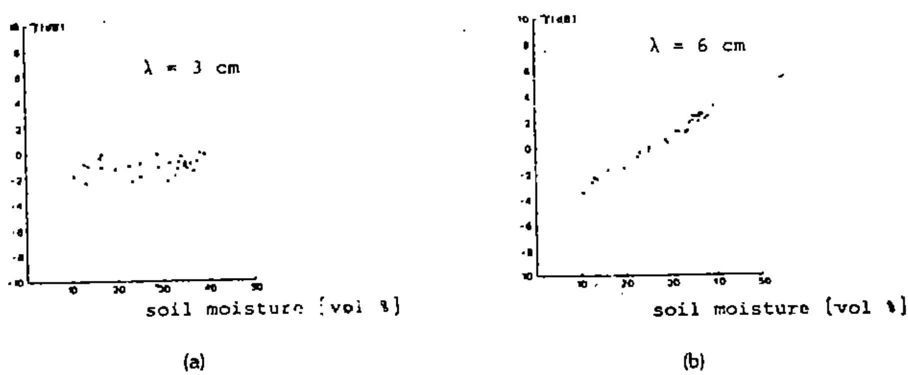


Figure 9: Simulated Performace of Spaceborne Radar at 10° Incidence Angle for Soil Moisture Determination of Vegetation Covered Terrain at 3 cm Wavelength (a) and at 6 cm Wavelength (b).

and/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 Begin *et al.* (1983). The use of bands X and C led to a good separation of the classes "water", "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 brekscattered signals the use of the variations of the texture did *not* improve the classification. Hoekman (1984) showed the ability 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 maas. Moreover, texture appeared to be an important discriminating tool for forests. An example of the use of polarization for vegetation analysis is provided by Riom *et al.* (1981). 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° 10 N and 117°50 E): it is characterised by the presence of Nypah with the help of microwave data. Indeed, *Nipah* fruitcans is one of the most common, widely distributed, and useful palms of the mangrove forest. It provides valuable products to traditional people living aside 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 L 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. F1 is located on a clastic terrain, F2 on a mixed terrain (Sabins, 1982) and the

Figure 10. SIR-A Imagery of Berau River In East Kalimantan

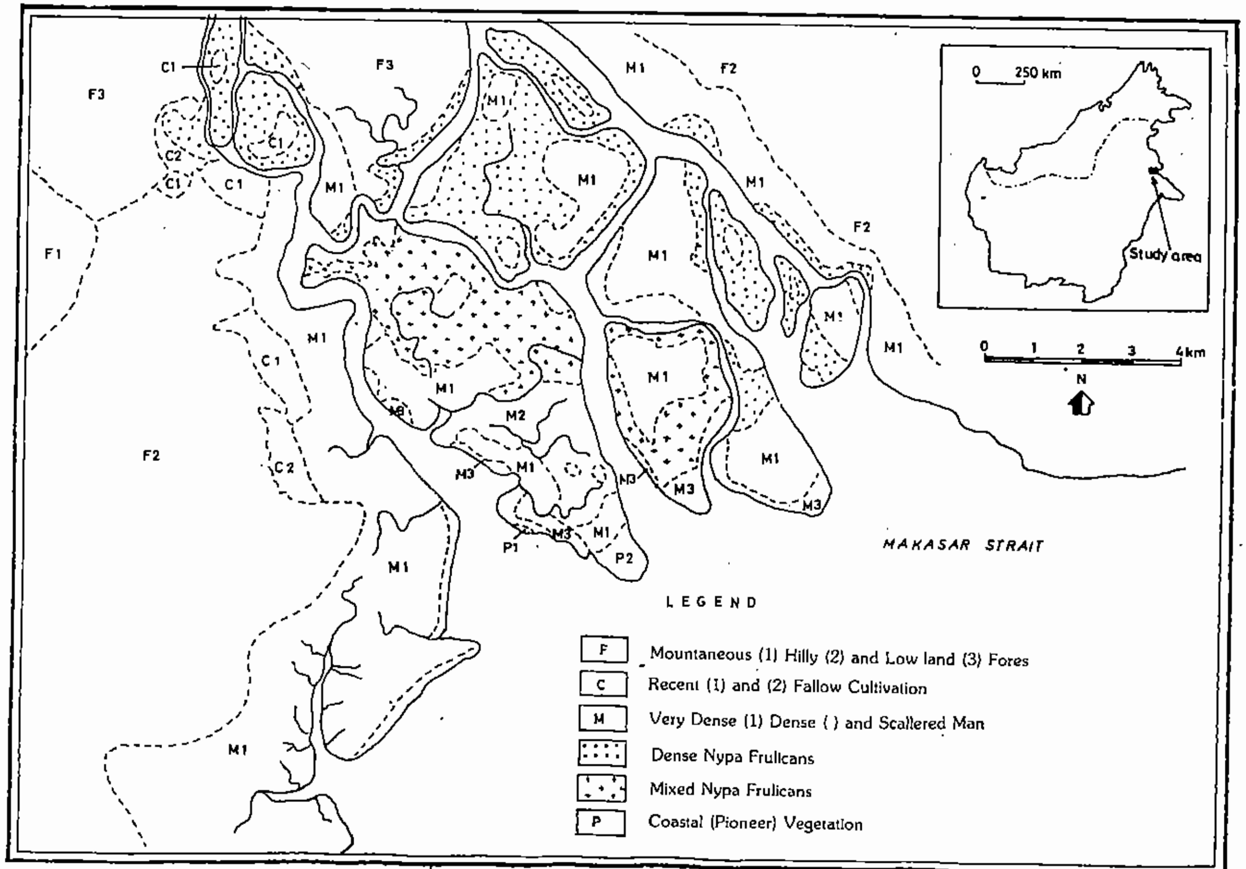


Figure 11. Map of the Vegetation in the Deltaic Area of Berau River in East Kalimantan (from Panchromatic Photo 1 : 100.000)

mangrove forests on an alluvial terrain.

2. The cultivation areas cannot be discriminated from the forests F which border them.
3. A "corner effect" induces the presence of very narrow coastal strips, due to the coasts facing in the direction of the radar.
4. The presence of a very bright head-land on the radar imagery may be due to a very important flooding of this, maybe newly created, area (Engheta and Elachi, 1982).
5. The very good delineation of the *Nipah* areas.

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

TABEL 1 : COMPARATIVE PHOTO–INTERPRETATION OF PANCHROMATIC PHOTOGRAPHS AND SIR–A IMAGES.

Type of vegetation		Panchromatic photography	SIR–A
Forest	Mountainous F1	Strong relief Same type of tress (more or less homogeneous)	Strong relief (Shadow, foreshortening): VGI
	Hilly F2	Smoother relief	Rough granulation < F1 relief modulated: VGI
	Low land F3	No relief: stronger variations of the tree heights and of the grey tones: larger crowns.	Rough granulation: no apparent influence of relief: GI
Fallow Cultivation	Recent C1	Mosaic of geometrical shapes with homogeneous grey tones	No identification of C1 and C2
	Old C2	As C1, but similar grey tones for adjacent parcels: regrowths	
Mangroves (Tree like populations)	M1	Small dense crowns, dark tones, less granularity than for F. 60% of the mangrove area	Very fine granularity salt and pepper, dark to light tones: GI
	M2	As M1 but with lighter tones	Confused with M1
	M3	Scattered trees on some coasts light tones: pioneer tress	No identification
Nipah fruticans	Dense N1	No granularity, medium to dark grey tones, often mottled with similar grey tones: homogeneous	Dark grey tone, slight granularity: VGI
	Mixed N2	As N1 but less homogeneous	As N1 but lighter: GI
Coastal areas	P1	Very fine granulation light tones, low vegetation	White narrow coastal strips: GI
	P2	No granular, uniform slightly mottled tones, low vegetation	No identification (newly created area)

Note: VG1 = very good identification and G1 = good identification.

conclusion of this study is the very good discrimination of the *Nipah* fruticans on the SIR—A imagery; quite more easily than with the considered panchromatic photographs. Thus, radar igamery (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 translocation of photosynthatic process from green leaves to fruits in the reproduction process than green leaf area index, a parameter that controls the visible and infra-red vegetation properties. It is through their geometric and electric characteristics that vegetation biomass and structure can be analysed 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 SIR—A configuration is very efficient for *Nipah* palm delineation but not for the other landscape units.

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