USING MIMICS TO MODEL L-BAND SAR BACKSCATTER FROM A PEAT SWAMP FOREST

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KHALI AZIZ, H. & WHITE, K. 2003. Using MIMICS to model L-band SAR backscatter from a peat swamp forest. The study was aimed at improving understanding of radar backscatter from peat swamp forest using MIMICS-I model. Two satellite scenes of the Japanese Earth Resources Satellite (JERS-1) SAR, acquired in dry and wet seasons, covering Pekan peat swamp forest in the state of Pahang, Malaysia were used. MIMICS-I model results were generated for L-band radar with Horizontal-Horizontal (HH), Vertical-Vertical (VV) and Horizontal-Vertical (HV) polarisations. The peat swamp forest floor was modelled either as an electromagnetically equivalent bare surface soil (dry season) or flooded with water (wet season). To understand the relative importance of the various parameters covering the soil, vegetation and environmental inputs on the forest backscatter, a sensitivity analysis was performed. Following that modelling was carried out to understand the backscatter characteristics of peat swamp forest. Results of the sensitivity analysis showed that parameters of the canopy layer contributed significantly to radar backscatter. The results of simulations showed that L-band microwave energy was capable of penetrating the canopy to the ground layer, as shown by significant trunk-ground contributions in both flooded and non-flooded forest conditions. This suggests that L-band SAR data can be used to extract forest stand information such as density and biomass from peat swamp forest.

Key words: Synthetics Aperture Radar - L-band radar - sensitivity analysis

KHALI AZIZ, H. & WHITE, K. 2003. Mengguna MIMICS untuk membuat model jalur L SAR daripada hutan paya gambut. Kajian ini bertujuan untuk meningkatkan kefahaman mengenai radar backscatter untuk hutan paya gambut menggunakan model MIMICS-I. Kajian dijalankan di kawasan Pekan, Pahang, Malaysia menggunakan dua data imej satelit JERS-1 SAR (Japanese Earth Resources Satellite) yang diambil pada musim panas dan hujan. Simulasi model MIMICS-I adalah berdasarkan radar jalur L dengan polarisasi HH (melintang-melintang), VV (menegak-menegak) dan HV (melintang-menegak) dengan andaian kawasan hutan sama ada sebagai kawasan kontang (sewaktu musim panas) atau kawasan berair (sewaktu musim hujan). Analisis sensitiviti dilakukan terlebih dahulu untuk mengetahui kadar

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kepentingan input parameter permukaan tanah, tumbuhan dan persekitaran terhadap jumlah koefisien backscatter hutan paya gambut. Keputusan simulasi model menunjukkan bahawa parameter lapisan silara pokok mempunyai pengaruh yang bererti terhadap backscatter radar. Keputusan daripada simulasi model juga menunjukkan bahawa tenaga gelombang mikro jalur L dapat menembusi lapisan silara pokok terus ke bumi seperti yang ternyata daripada sumbangan batang-tanah yang bererti dalam hutan berair dan tidak berair. Kajian ini menunjukkan bahawa data jalur L SAR boleh diguna untuk mendapatkan maklumat dirian hutan seperti kepadatan dirian dan jisim kawasan hutan paya gambut tropika.

Introduction

Several radar backscatter models have been developed to analyse microwave scattering by trees and forests as a function of the radar system parameters (Fung 1979, Lang & Sindhu 1983, Eom & Fung 1984, Richards *et al.* 1987, Karam & Fung 1988, Ulaby *et al.* 1990, Wang *et al.* 1995). The development of such models is important in order to help understand microwave interactions with forests and to explain observed backscatter from a wide range of forest ecosystems. The two most widely used models in forest studies are Santa Barbara model and MIMICS (Michigan Microwave Canopy Scattering). This study was aimed at improving understanding of radar backscatter from peat swamp forest using the MIMICS-I radiative transfer model.

Romshoo and Shimada (2001) used MIMICS-I to study forest biomass characteristics in tropical forest. Imhoff (1995) used MIMICS-I and forest canopy data from tropical and subtropical broad-leaved forests to simulate a series of forest stands having equivalent aboveground biomass while still exhibiting substantial structural differences. Results of these studies indicate that structure can have a considerable effect on the Synthetics Aperture Radar (SAR) return from forests with equivalent aboveground biomass. Differences in backscatter of up to 18 dB were predicted for some bands and polarisations. A forest canopy structural descriptor derived from vegetation surface area to volume ratio (SA/V), which is a measure of structural consolidation, appears to explain differences in backscatter. In many vegetation stands, structural consolidation is directly related to an increase in biomass during the thinning phase of forest succession. This structural effect may explain the good relationships between SAR backscatter and biomass.

Materials and methods

Study area

Two scenes of the Japanese Earth Resources Satellite (JERS-1) SAR data covering Pekan peat swamp forest in the state of Pahang, Malaysia were used for the model assessment. The data were acquired during both dry (17 July 1993) and wet (13 October 1993) seasons. Ecologically, peat swamp forest is a unique forest formation, occupying and thriving in a niche of waterlogged, imperfectly drained land. The forest is generally characterised by trees with huge buttresses, stilt roots and spreading roots for anchoring in soft peat soil. The forest experiences periodic flooding and in the rainy season the whole forest floor is covered with water up to about one meter deep. Field data collected in 10 sample plots each measuring 60 × 60 m indicate that the five most diverse tree families in the study area were *Lauraceae, Euphorbiaceae, Guttiferae, Rubiaceae* and *Myristicaceae.*

Model

MIMICS-1 is a fully polarimetric, first-order radiative transfer model for simulating backscatter from tree canopies. It accounts for the homogeneity of the media by averaging Stokes matrix over statistical distributions characterising the size, shape, and orientation of the canopy elements. A detailed explanation of radiative transfer theory is given by Ulaby *et al.* (1981). The model takes into consideration scattering processes that involve single scattering by each region and double scattering by pairs of regions. The complete derivation of this model is given by Ulaby *et al.* (1990). MIMICS-1 is designed to function for a frequency range extending from approximately 1 to 10 GHz and over a wide range of incidence angles (McDonald & Ulaby 1993). The MIMICS-I models tree canopies that have continuous or closed crown layer geometries, and it has been verified in several modelling studies (McDonald *et al.* 1990, 1991). However, to date, it has not been tested in tropical peat swamp forest environments.

MIMICS-1 model results were generated for L-band radar with Horizontal-Horizontal (HH), Vertical-Vertical (VV) and Horizontal-Vertical (HV) polarisations. A range of incidence angles between 10° and 70°, which covers the range of most typical SAR measurements, were used. However, for comparison only results based on analyses carried out at a fixed incidence angle of 35°, in accordance with the JERS-1 SAR incidence angle, are reported in this paper. Throughout the analyses, the peat swamp forest floor was modelled either as an electromagnetically equivalent dry surface (during dry season) or flooded with water (during wet season). The input parameters for the model were divided into four major categories, namely, tree, environment, ground and sensor inputs as shown in Table 1. The first three categories are critical in the sense that they vary depending on forest conditions.

Sensitivity analysis

To understand the relative importance of the various parameters covering soil (ground), tree (vegetation), sensor and environmental inputs on the total backscatter coefficient for tropical peat swamp forest, a sensitivity analysis was performed. This is important as the model has never been tested in a peat swamp forest environment. A total of 20 input parameters related to the vegetation and soil were tested. They were varied one at a time across relevant intervals. Sensor configuration corresponded to the JERS-1 SAR (i.e. frequency of 1.27 GHz, HH-polarisation and 35° incidence angle). Simulation was based on a soil ground layer. The results were used to group the parameters into different classes. The first class comprised parameters with major influence, i.e. the radar backscatter coefficient varied > 0.5 dB over the interval. The second class had parameters which had minor influence, i.e. with variation < 0.5 dB over the interval.

Table 1 Characteristics of peat swamp forest in Pekan, Pahang, Malaysia used in MIMICS-I modelling

Property	Value
Tree constituents	
Leaf diameter	5.6 cm
Leaf thickness	0.045 cm
Canopy thickness	5.6 m
Orientation of tree constituents	
Trunk	8EXP(-8*THETA_c)
Leaf	0.5*SIN(THETA_d)
Primary branch	(1.230469)*SIN(THETA_c-30)**9
Secondary branch	(1.230469)*SIN(THETA_c-30)**9
Third branch	0.5*SIN(THETA_c)
Fourth branch	0.5*SIN(THETA_c)
Dielectric characteristics	
Trunk	45.0-j11.2
Leaf	28.3-j8.5
Primary branch	34.0-j8.5
Secondary branch	30.0-j7.5
Third and fourth branch	31.86-j8.93
Ground surface	25.0-j2.5
Ground and environmental characteristics	
Vegetation temperature	23 °C
Standing water temperature	25 °C
Standing water salinity (pH)	3.5
Soil condition	Silty clay
Soil particle composition	Sand = 40%, clay = 30%, silt = 30%
Soil temperature	22 °C
Soil correlation length	16.87 cm
Soil RMSE** height	1.27 cm
Soil volumetric moisture content	0.355 m^3/m^3

**RMSE = Root mean square error

The effect of flooded and non-flooded forest on backscatter characteristics

The backscatter difference between the dry (non-flooded) and the wet (flooded) seasons of the peat swamp forest as observed in the JERS-1 SAR images over the study area was much smaller than expected. Thus, modelling was carried out to understand the backscatter characteristics of peat swamp forest in flooded and non-flooded conditions. Simulation was carried out using different leaf densities based on information collected from the peat swamp forest with two different ground conditions, namely, soil and water ground layers. The average canopy density, trunk height and trunk diameter were 0.13 tree m^{-2}, 16.9 m and 25 cm respectively. A range of leaf densities from 100 (almost defoliated conditions) to 3500 leaves m^{-3} were simulated. The sensor configuration was based on the L-band JERS-1 SAR (frequency = 1.27 GHz, incidence angle = 35°, and HH-polarisation) while other parameters are as shown in Table 1.

Results and discussion

Sensitivity analysis

Results of the sensitivity analysis (Table 2) show that parameters of the canopy layer (including crown height, leaf density and number of primary branches) contributed significantly to radar backscatter. These parameters determine the penetration capability of the L-band microwave energy. However, leaf size and other small branches (secondary, third and fourth branches) only have minor influences on the radar backscatter.

L-band, with its relatively low frequency, was able to penetrate deep into the forest canopy and was therefore, more affected by large tree components such as the bigger primary branch. Other smaller tree components, such as leaves and small branches, did not affect radar penetration very much at this frequency. However, as canopy thickness increased (either due to the increase in crown height or in leaf density), more microwave energy was attenuated and thus, less backscatter was observed. It was also observed that parameters related to tree trunk, including trunk diameter and length, only had minor influences on radar backscatter. This is probably due to the fact that the trunk orientation was modelled as a vertical cylinder and the sensor was modelled as having HH-polarisation. For this trunk orientation, the backscatter coefficient will be more significant in the VV-polarisation configuration (Ford & Casey 1988). With regard to soil parameters, only soil moisture content showed a significant influence on radar backscatter whereas soil correlation length and soil root mean square error (RMSE) had only minor influences.

Table 2 Sensitivity of the backscatter coefficient to various MIMICS-I input parameters during modelling of the peat swamp forest stand

Parameter	Interval	Effect (dB)	Influence
Leaf moisture content	0.2 m^3/m^3	1.51	Major
Leaf thickness	0.01 cm	0.02	Minor
Leaf diameter	1 cm	0.08	Minor
Leaf density	200 leaf m^{-3}	0.80	Major
Crown thickness	2 m	0.72	Major
Trunk length	2 m	0.01	Minor
Trunk diameter	2 cm	0.01	Minor
Number of trunks	0.1 tree m^{-2}	0.03	Minor
Trunk moisture content	0.2 m^3/m^3	0.18	Minor
Number of primary branches	0.4 branch m^{-3}	0.70	Major
Primary branch length	2 m	0.72	Major
Primary branch diameter	2 cm	1.20	Major
Number of secondary branch	0.4 branch m^{-3}	0.33	Minor
Secondary branch length	1 m	0.35	Minor
Secondary branch diameter	2 cm	0.21	Minor
Third branch diameter	1 cm	0.34	Minor
Fourth branch diameter	1 cm	0.08	Minor
Soil moisture content	0.1 m^3/m^3	0.50	Major
Soil autocorrellation length	4 cm	0.04	Minor
Soil RMSE*	0.4 cm	0.29	Minor

*RMSE = Root mean square error

The effect of flooded and non-flooded forest on backscatter characteristics

One benefit of MIMICS-I is that besides total backscatter, it has the ability to predict separately the different backscatter components in the simulation results. Depending on the surface ground layer used in the simulation of this study, the different backscatter components were "direct-crown" (DIRC), "trunk-ground" (TG), and "direct-ground" (DIRG) interactions.

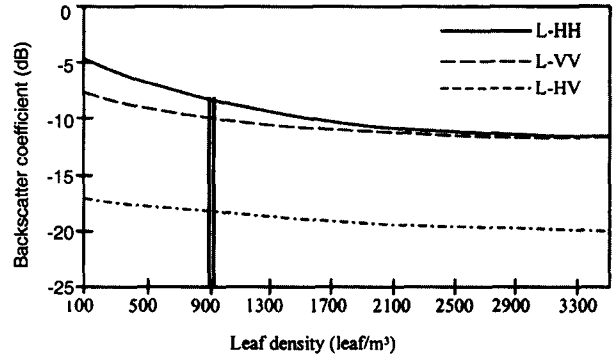
The effect of leaf density on the L-band radar backscatter for the different components simulated using MIMICS-I is presented in Figures 1 and 2 respectively for soil (non-flooded) and water (flooded) ground layers. Total L-band backscatter simulated by MIMICS-I based on different polarisations is shown in Figure 3. Two general trends were observed. First, predicted radar backscatter from the peat swamp forest was inversely proportional to leaf density (higher backscatter when the leaf density was low). Second, backscatter from water (flooded) ground layer was only slightly higher than soil (non-flooded) ground layer.

The results of simulations show that backscatter had an inverse relationship with leaf density in both soil (non-flooded) and water (non-flooded) ground layers. For HH-polarisation, double bounce scattering, such as trunk-ground interactions, dominated the backscatter at low leaf densities (Figure 1(a)). As leaf density increased, the double bounce effect became less important relative to volume scattering from the crown. This is in line with findings by Wang *et al.* (1995) who indicated that at an incidence angle of more than 30°, L-HH backscatter is dominated by volume scattering. However, in VV-polarisation configurations in this study, the contribution of trunk-ground interactions was not significant; instead the backscatter was dominated by direct-crown interactions (Figure 1(b)). For the cross-polarisation configuration, low backscatter dominated by volume scattering was predicted from direct-crown interactions (Figure 1(c)). Figure 3(a) presents total backscatter for the different polarisations based on soil ground surface. The highest and lowest backscatters were observed in HH-polarisation and HV-polarisation respectively.

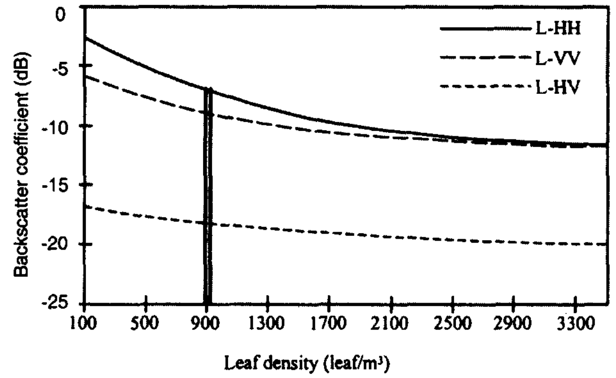
A peculiar but predictable aspect of forest backscatter was the enhanced backscatter observed when there was standing water under the trees. This is due to enhanced reflection from the tree trunks to the ground and then to the radar, or vice versa; in other words a double bounce mechanism (Ahmed & Richards 1989). If a layer of water (a specular surface) underlies the trees, an enhanced double bounce would be expected.

At lower leaf densities and HH-polarisation of water ground layer, trunk-ground interaction dominated the backscatter, indicating an enhanced double bounce effect by about 3 dB. As the leaf density increased up to about 800 leaves m^{-3}, the contribution from direct-crown scattering was greater, but the contribution from trunk-ground scattering was still significant (Figure 2(a)). However, when backscatters for soil (non-flooded) and water (flooded) ground layers were compared, a small difference was observed. For instance by taking leaf density as 900 leaves m^{-3}, the backscatter coefficients of HH-polarisation for soil (non-flooded) and water (flooded) ground layers were - 8.43 and - 7.14 dB respectively; a difference

1983). This is expected because radar images produced by like-polarised returns are usually different from cross-polarised returns due to variations in the interaction mechanisms involved (Fung & Ulaby 1983). In like-polarisation radar systems, strong returns occur when scatterers are oriented in the same direction as the polarisation of the incidence wave. The difference of backscatter coefficients between HH- and VV-polarisations in this study was highest at lower leaf densities (about 3 dB), but the difference decreased toward a common value as leaf density increased. This could be due to the effects of branch orientation. HH-polarised backscatter increased as branch orientation became horizontal. For the peat swamp forest, in which branch orientation (primary, secondary, third and fourth) was distributed over a wide range of angles, backscatter coefficient of HH was slightly higher than VV. It is also inferred that there was little de-polarisation of radiation, as the cross-polarised backscatter was low.



(a) Soil as ground layer



(b) Water as ground layer

Figure 3 L-band total backscatter versus leaf density for the different polarisation configurations, (a) based on soil as ground layer, and (b) based on water as ground layer.
Vertical line shows the most representative leaf density in Pekan peat swamp forest.
HH = Horizontal-horizontal polarisation
HV = Horizontal-vertical polarisation
VV = Vertical-vertical polarisation

Conclusions

L-band microwave energy was capable of penetrating the canopy to the ground layer, as shown by the significant trunk-ground contribution in both flooded and non-flooded forests at low leaf densities. This suggests that under the right conditions, L-band data can be used to extract forest stand information such as stem density and biomass, as suggested by other workers (Wu 1987, Hussin *et al.* 1991, Luckman *et al.* 1997). Results from this study also indicate the potential of using SAR data to detect the extent of flooded forest. Similar encouraging results were also reported by Wang *et al.* (1995) from a study conducted in the Amazonian tropical forests.

Leaf density, as predicted by MIMICS-I, had a significant influence on radar backscatter. At low leaf density, higher L-band backscatter was observed, suggesting more canopy penetration by the microwave energy and thus allowing more interactions with subcanopy components and a greater sensitivity to double bounce beneath flooded forest. However, MIMICS-I predicted that due to the higher leaf density of peat swamp forest, the increase in radar backscatter with the presence of water was only minor, although still greater than the observed difference. The scenario adopted to simulate a flooded forest appeared to over predict the resulting increased backscatter. The magnitude of backscatter was also determined by the polarisations used. MIMICS-I predicted that the backscatter coefficient for the cross-polarisation configuration was always lower than the like-polarisation. Within like-polarisation configuration, HH-polarisation exhibited a higher backscatter coefficient than VV-polarisation.

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