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Employing SAR for Biomass Retrieval From Tropical Forests of Southeast Asia

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Abstract: Because of their importance to earth system, retrieval of biophysical parameters using the SAR systems is gaining urgency and importance. Exploiting the potential of SAR, we validate the MIIMICS model with a time series of JERS-1 SAR data. Theoretical modeling of the radar scattering from the vegetation is employed to understand the radar-vegetation interaction mechanism and to simulate the effects of the canopy architecture on the radar backscattering for the radar sensor configuration of the JERS-1 and ERS. The field data measured from 12 sample plots over two tropical forest sites in Chiang Mai, towards north of Thailand is used for driving the simulations. The results show that for JERS-1 SAR, the main contribution is from the interaction between the trunk and the ground and in forests where the main biomass is concentrated in the trunks, L-band SAR holds a great promise. Further, the canopy structure and architecture has been seen to have a paramount influence on the radar backscattering from tropical forests for both L-band (JERS-1) and C-band (ERS) sensors. The sensitivity of the radar to soil moisture can not ignored at lower angles of incidence, especially, under moist forest floor conditions. Both the sensors are appreciably sensitive to the woody biomass with JERS-1, because of better interactions with the woody constituents of the canopy, showing a better sensitivity. In case of JERS-1, the sensitivity is quite high for the regenerating forests. In case of ERS, though we find that it is sensitive to the biomass upto 50 tons/ha but the sensitivity is appreciably reduced after that.

Key Words : Scattering mechanisms, vegetation and surface characteristics, diameter at breast height (dbh), tree structure and biomass, bio- and geo-physical parameters

1. Introduction

Though water and carbon cycles are very important for the quality and the quantity of different life forms on our planet but we have till date no means for mapping the spatial distribution of the soil moisture and biomass on a regional or continental scale on an operational level. The knowledge about the amount and distribution of biomass is important, not only for understanding the carbon budgets, but also for other land surface processes related to water and energy budget. Carbon sequestration is thought to be promising means of reducing atmospheric carbon dioxide, the focus of Kyoto Protocol, which aims to cut the world‘s greenhouse gas emissions such as carbon dioxide and methane. A major constraint to successful forestry based carbon offset programs is the lack of reliable, accurate and cost effective methods for monitoring carbon storage. There is a large uncertainty in the estimates of carbon fluxes due to changes in tropical forests. The two estimates of biomass of tropical forests by Brown and Lugu (1991) from two different data bases are markedly different.

Though remote sensing technology, especially the Synthetic Aperture Radar (SAR) systems, have been exploited for biomass estimation particularly in the North America and Europe (Dobson et al., 1992, Le Toan et al., 1992), but very little work,if at all, has been attempted in the tropical forests of the Southeast Asia. In continental Southeast Asia, the forest covers approximately 70 million hectare or 30% of the toal land area. Low altitude forests are estimated to contain 60% of the total above ground carbon in world forest vegetation. Realizing the importance of these forests in the earth system's context, NASDA, in continuation of the Global Rain Forest Mapping Project (GRFM) and Boreal Forest Mapping Project (BFM), has initiated the SouthEast Asian Forest

Mapping Project. JERS-1 SAR mosiac of the region (Shimada et al., 2001) has been recently made public for full exploition by the reseach community. Radar remote sensing of the vegetation is not a straight forward case. The radar backscatter is not only sensitive to the total biomass of the trees but is also sensitive to the woody strucuture. This degrades the correlative relationship between the radar backscatter and the biomass.

2. Study Area Description

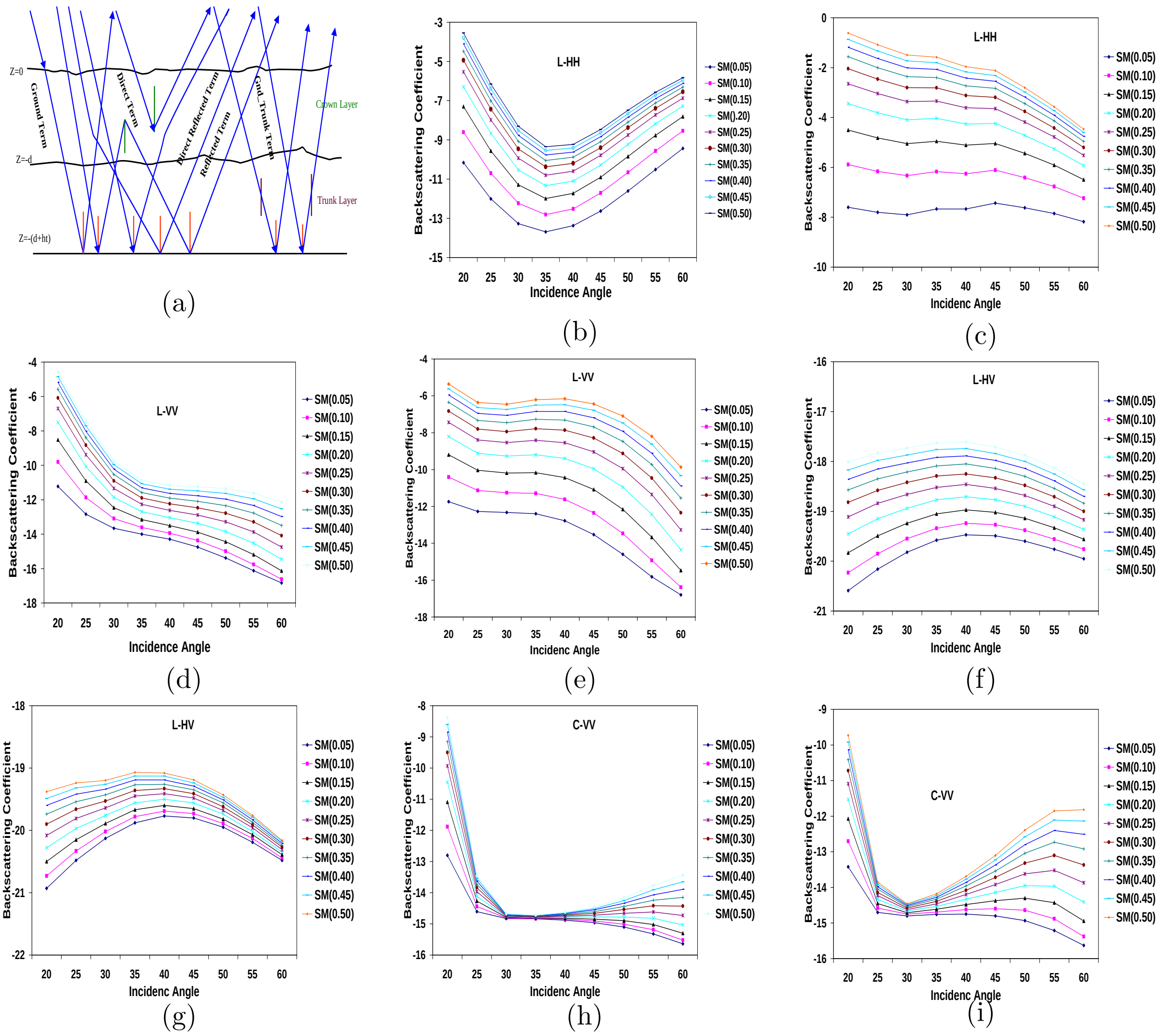
A few study sites have been chosen in Thailand for the estimation of the forest biomass using spaceborne SAR data. Two sites are in the northern Thailand, Huai Rai and Huai Som and a few sites are in the western forest regions of the Thailand near Kachanapuri. The forest near Huai Rai and Huai som covers approximately 40 hectares each. A forest area spread over 2 hectares was chosen for forest biophysical parameters measurement. The area is located at an elevation of 485 m a.s.l and receives a annual rainfall of 1100 mm. The exact location of this site, the edaphic, climatic, physiographic and vegetation description of this site has been discussed by Tennigkeit (2000) and Shakil et al. (2001). The forests are predominantly dry Dipterocarpus which is a deciduous broad leaved forest type. The stands show sporadic, discontinuous crown cover with large canopy openings as well as the stratification of whole stand into two layers. At Huai Rai, a total of 12 sample plots were set up to measure a number of vegetation parameters. The inventory design and the reasons for its choice are discussed in details by Tennigkeit, 2000. In a 40 m * 40 m plot, all the adult trees with dbh $\geq$ 5 cm were recorded. while as in the sapling subplots (10 m * 20 m), trees with heights$\geq$ 1.3 m and dbh $\geq$5 cm were recorded. In seedling inventory subplot (2 m * 20 m), tree with heights less than 1.3 meters were recorded. All the plots were protected from disturbances during the field work. Investigated tree parameters include species-wise dbh, Density, Height, crown heights, crown radii,horizontal distribution, crown light availability. In order to get the whole range of parameters used for driving the model simulations, some empirical models (Brown, S., 1997) were used based on the measured data. Some of the parameters were also estimated using the allometric equations from some other literature.

3. SAR Data Processing

six scenes of the JERS-1 SAR data over the area were processed for the MIMICS model validation. The data were recorded during 1997 (26 Jan.,11 Mar.,24 April and 17 Oct.) and 1998 (26 Feb. and 21 Aug.). To minimize the topographic effects and to compute the correct local incidence angle, we used a 1:250000 scale Digital Elevation Model (DEM) of the area. Slope and aspect were generated from the DEM and were used to calculate the local incidence angle for every pixel in the study area.

4. Radar-Vegetation Scatter Modelling

The meaningful interpretation of the radar remote sensing data could be achieved only when we have a thorough understanding of the various scattering mechanisms that contribute to the backscatter. During the past few decades, we have seen the development of a No. of volume scattering models which can be used to simulate the radar backscattering under different vegetation and surface conditions. They have been based either on radiative transfer theory (Ulaby et al., 1990, Karam et al.,1995),or distorted born approximation (Lang et al. 1983) or some are based on semi-empirical relationships . We used the MIMICS, MIchigan MIcrowave Canopy Scattering model (McDonald et al. 1993, Ulaby et al., 1990) for calculating the backscatter from the vegetation. The solution is based on the first order solution of the radiative transfer equation of a tree canopy comprising a crown layer, a trunk layer and a rough surface ground boundary. The problem is solved in two parts. First,the problem of backscatter from a two layer canopy over a specular ground surface is addressed. Then an appropriate term is added to account for the backscatter directly from the ground as attenuated by the vegetation. Mathematically, the backscattered intensity $I_t^s(\mu_0, \phi_0, \pi)$ propagating in a particular direction is related to the incident intensity $I_0(\mu_0, \phi_0, \pi)$ through the transformation matrix $T_t(\mu_0, \phi_0, \pi)$ as follows:



(a) (b) (c)

(d) (e) (f)

(g) (h) (i)

Fig. 1 This composite figure shows;(a)different scattering mechanism accounted in MIMICS;(b-c)Radar-vegetation interaction as function of incidence angle, soil moisture and dbh (5cm(b) and 60cm(c)) for L-band HH Polarization ;(d-e)same as previous but for VV polarization;(f-g)same as previous for HV polarization;(h-i) for C-band VV polarization.

$$\langle I_t^s(\mu_0, \phi_0, \pi)\rangle = \langle T_t(\mu_0, \phi_0, \pi)\rangle_c I_0(\mu_0, \phi_0, \pi) \qquad (1)$$

Figure 1(a)illustrates a few of the components of $T_t(\mu_0, \phi_0, \pi)$. Applying the iterative solution for the backscatter case and adding the contribution from the ground surface yields the first order solution (McDonald et al. 1993)

The forest canopy in our study area is quite transparent and the proportion of gaps in such a type of young regenerating dry Dipterocarpus forests could be as high as 40% (Sahunalu et al., 1993). Due to this structure of the forests, only single layer has been modelled with the assumption that the understory would have small effects for JERS-1 SAR (Silva et al., 1997).

5. Results and Discussion

(1) Comparison With Observed Backscattering Data

The MIMICS model was driven by a host of vegetation and surface parameters which were either measured from the ground or computed using the alometric equations (Brown, 1997)or using the values from the literature. The simulated values were compared with the JERS-1 SAR

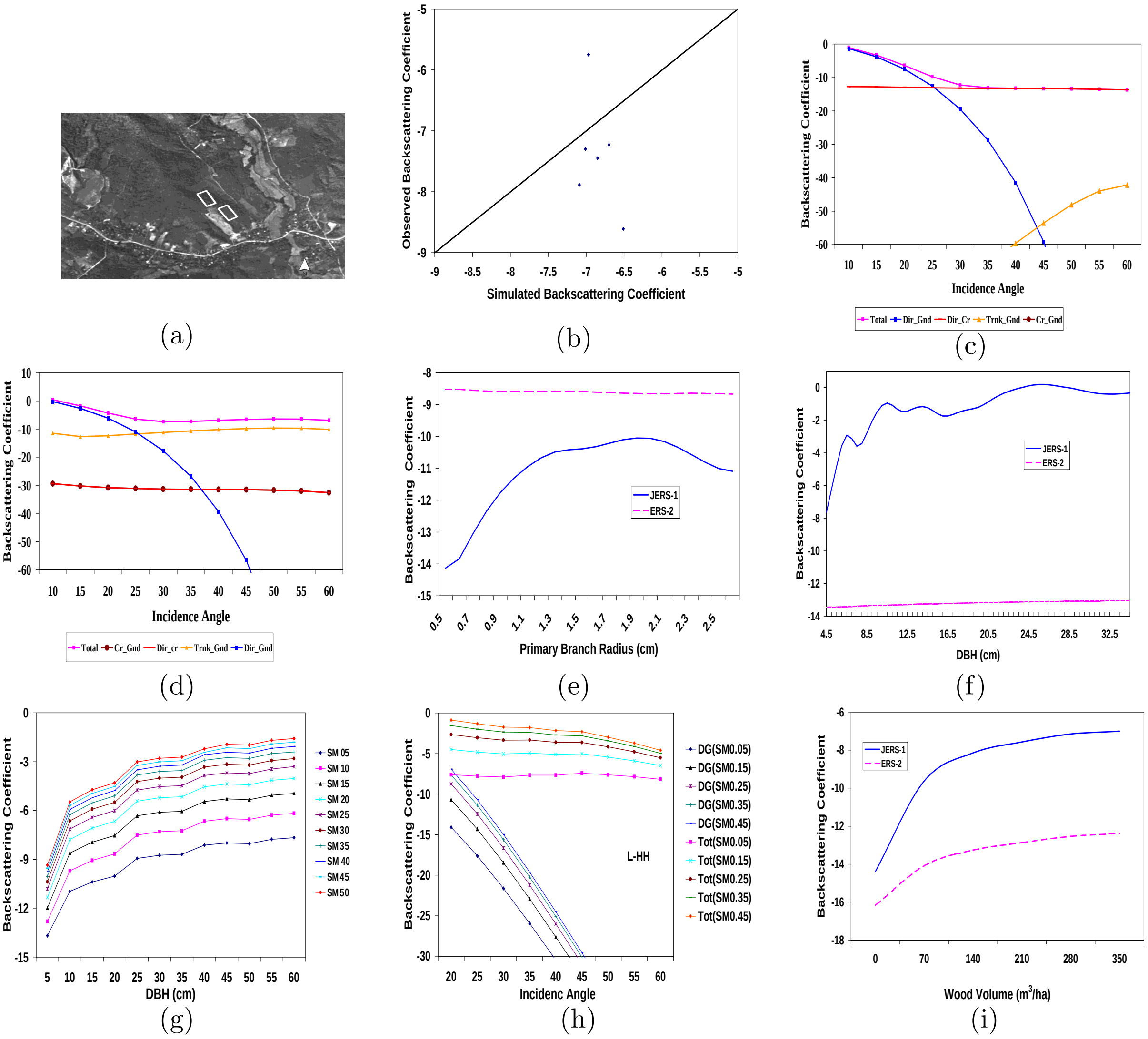


Fig. 2 This composite figure shows : (a) field sites; (b) MIMICS model validation with JERS-1 SAR ; (c-d) the contribution of different scattering mechanisms for ERS and JERS-1 SAR respectively as a function of incidence angle;(e-f)influence of branch radius and dbh on JERS and ERS data;(g-h)radar response as a function of soil and vegetation parameters;(i) Biomass relationship with SAR for JERS and ERS SAR data

data for six dates as detailed above. The Figure 2(b) shows the comparison between the observed and the simulated values. Though, on most of the dates, the agreement is reasonable but on couple of days, the difference is more than 2 dB. The disagreements could be due to many reasons, one being the inadequate information about the surface characteristics viz., soil moisture and roughness characteristics. For all these days, we assume similar surface conditions, which could be varying due to dynamic soil moisture conditions over the area.

(2) Data Analysis and Discussion

The study has been carried out to understand the radar-vegetation mechanisms in the tropical forests of southeast Asia using MIMICS model validated by JERS-1 SAR data. Furthermore, the JERS-1 SAR and ERS SAR configurations have been tested to determine the structural influences of vegetation on radar backscattering. For analyzing the effects of a particular vegetation parameter on the radar backscattering, all input parameters except the one under study are kept constant. This is important to know the effects of structural elements while keeping the total biomass constant. In order to get an in-depth understanding of the radar-vegetation interactions, we conducted simulations under an No.of possible scenarios but due to space limitation, we would be only discussing the important findings. Nevertheless, we would refer them on and off during the discussions and/or while drawing up the conclusions

Transmissivity of the JERS-1 and ERS radars under the given field conditions is appreciable due to the presence of gaps in the canopy (Romshoo et al. 2001). The canopy density of the dry dipeterocarpus forests is low compared to the other moist tropical forests due to poor site conditions and relatively long dry spells. This makes the forest floor quite visible to the radar signals and under such conditions, the surface conditions would have a significant impact on the total radar backscattering (Dobson et al., 1992). The Figure 1 (b-i) shows radar response under different vegetation and surface conditions for L-and C-bands at different polarizations and incidence angles. Here for a given biomass level determined by dbh, we simulate radar response w.r.t change in the incidence angle and soil moisture. For L-band, we show the radar response for each linear polarization at low vegetation biomass (dbh=5cm) and at higher biomass (dbh=60cm). Due to space limitations, we show it for only VV polarization for the C-band radar. At L-band HH polarizations and low biomass, we observe a peculiar radar response as shown in Fig. 1(b). At lower angles of incidence, the increase of backscattering coefficient is solely due to the increase of the soil moisture but towards higher incidence angles, the increase in the backscattering coefficient is due to the double bounce scattering from the ground-trunk interface. At intermediate angles of incidence, we observe a dip in the response curve due to moderate influence of the soil moisture and trunk. At higher biomass levels (Fig. 1(c)), we observe a diffuse scattering response and the increasing backscattering coefficient with increasing soil moisture, in not solely due to the contribution from direct soil term but mainly because of stronger double bounce term (Fig. 2(d & h)). For VV polarization, the radar response shows a specular pattern with a significantly low soil contribution at higher angles of incidence. The vegetation-ground interactions remain constant for a large range of incidence angles except the very high incidence angles ($\rangle\, 50^0$). The vegetation contribution, both from crown and trunks, gets increased with the increase of incidence angles and the surface soil moisture. The direct contribution from the soil is insignificant. For L-band, HV polarization, the soil contribution even at lower angles of incidence is negligible while as the main contribution is due to multiple scattering from the crown constituents under both low and high biomass conditions. For C-band vv polarization radar, the soil contribution is obviously insignificant for both high and low biomass conditions even at lower incidence angles. The main contribution is from the crown constituents like primary and secondary, tertiary and higher order branches.

Furthermore, radar backscattering besides being sensitive to the biomass is also sensitive to the structural attributes of the vegetation. This could have adverse effects on the biomass estimation using SAR data. Figure 2(e-f) shows the sensitivities of the L- and C-band radar to the dbh and primary branch dimensions. The sensitivity to other vegetation characteristics in these forests have been worked out in details by Romshoo et al. 2001. The L-band radar (JERS-1 configuration) is sensitive to the trunk and branch dimensions while being almost insensitive to leaf structure and leaf moisture. While as the C-band radar (ERS configuration) is insensitive to the trunk and branch characteristics (Fig.2 e-f)and very sensitive to the leaf structure and moisture . Both JERS-1 and ERS shows appreciable sensitivity to the change in the crown depth (Romshoo et al. 2001). This is due to the fact that the main contributions for the JERS-1 SAR and ERS SAR are dominated from the woody and leafy constituents respectively. This indicates that in forests, where most of the biomass is concentrated in the tree boles, JERS-1 shows a promise for biomass estimation.

Fig. 2(i) shows the JERS-1 and ERS SAR backscattering relationship with the wood volume. It is again reiterated here that the forests under study are regenerating forests with biomass less than 50 ton/ha. The higher levels of biomass have been simulated by incrementing the various growth parameters taken from the literature. It could be seen from the figure that JERS-1 shows higher sensitivity to the biomas as compared to the ERS. The JERS-1 sensitivity is quite good even up to higher levels of biomass while as the ERS backscattering shows saturation at very low biomass levels. Further, the dynamic range of the JERS-1 backscattering is quite higher than that of the ERS. The sensitivity of the C-band ERS SAR to biomass could be due to the smaller dbh of the regenerating forest crop (less than 15 cm). The sensitivity of the ERS to the lower biomass levels could be also due to the ground contribution at lower levels of the biomass as there are appreciable gaps in the canopy.

6. Conclusions

The radar-vegetation interactions as unrevealed by the theoretical model simulations provide us an in-depth understanding of the various scattering mechanisms involved in the tropical forests. The dominant contribution from woody elements at L-band HH polarization holds a promise for biomass estimation in forests where main biomass is concentrated in the woody parts. With ALOS in the orbit by 2003, we would be having L-band SAR with all the linear polarizations and could facilitate a polarimetric and interferometric approach for the biomass estimation.

The scattering model simulations tell us that there is a structural control of the backscattering behavior for both JERS-1 and ERS radars. Because of the longer wavelength, the L-band SAR is sensitive to the trunk and branch elements while as C-band SAR is sensitive to the leaf structural and biomass attributes. We would have to derive relationships between the radar backscatter and biomass which are independent of the structural influences. The simulation studies conducted under different radar, vegetation and surface conditions supported by the observations from the space would facilitate the development of an index that could account for these structural influences.

The sensitivity of both these radars to biomass is appreciable at lower levels of biomass, with JERS-1 being more suitable for biomass estimation and monitoring due to higher sensitivity, in these tropical dry Dipterocarpus regenerating forests. The sensitivity of the C-band radar to the biomass at lower levels of biomass is related to the prevalence of gaps in these young tropical forests and also due to the small dimensions of the tree boles to which C-band has been reported to be sensitive. As expected, the ERS sensitivity to the higher biomass levels is significantly dampened while as the JERS-1 SAR shows some sensitivity, even though week, towards higher values of the biomass (around 200 tons/ha).

In order to have a full dynamic range of the biomass levels and that of the radar backscattering response, we plan to study as many No. of field sites as possible so that a robust algorithm for the biomass estimation from the tropical forest is developed. Depending upon the availability, we aim to use multi-sensor radar radar, both from the space-borne and air-borne sensors.

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