

MICROWAVE BACKSCATTER AND ATTENUATION DEPENDENCE ON LEAF AREA INDEX
FOR A CENTRAL CALIFORNIA RICE FIELD

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Abstract

Wetlands are important for their role in global climate as a source of methane and other trace gases. As part of the effort to determine whether radar is suitable for wetland vegetation monitoring, we have studied the microwave backscatter and attenuation dependence on leaf area index (LAI) for vegetation in flooded areas, specifically flooded rice fields. We find that the radar return from a flooded rice field does show dependence on LAI, primarily in the form of a decreasing VV cross section with LAI at C-band. A simple model for scattering from rice fields is derived and fit to the observed HH and VV σ^0 data. The model fit showed that double bounce scattering dominates at all LAI. The model fit was used to calculate the canopy path attenuation as a function of LAI. The C-band VV polarization sensitivity found here to LAI indicates that radar may indeed be a useful tool in remote sensing of wetlands.

1 Introduction

Wetlands are important for their role in global climate as a source of methane and other trace gases. Primary controlling factors for methane emission include vegetation characteristics and presence of surface water [1]. The unknown spatial and seasonal extent of these controlling factors in northern wetlands remains one of the largest sources of uncertainty in many current global methane budgets. Hence, it is desirable to apply remote sensing techniques to map these factors over large regions, allowing scaling of local methane flux measurements to regional scales. With the availability of ERS-1 and JERS-1 and the planned flight of RADARSAT, imaging radar is a candidate for this application. There has been much work done on using radar to measure forest properties. It has been shown that radar is sensitive to the vegetation biomass in the case of woody vegetation (e.g., trees) for low to moderate biomasses [2] and has also been shown that radar is sensitive to surface water under trees [3]. Most measurements of herbaceous vegetation (e.g., grasses) by radar have focused on agricultural crops without surface water present. Ulaby et al. [4] found that radar is indeed sensitive to leaf area index and Bouman [5] reported sensitivity to biomass and canopy height. Radar's response to herbaceous vegetation in wetlands is less well documented, although Ott et al. [6] presented evidence that multipolarization SAR can distinguish wetlands vegetation types in a mid-latitude setting, and Pope et al. [7] used radar to identify flooding in tropical sedge and grass wetlands.

As part of the effort to determine whether radar is indeed suitable for wetland vegetation monitoring, we have studied the microwave backscatter and attenuation dependence on leaf area index (LAI) for vegetation in flooded areas. Because many factors in addition to LAI can affect the radar response,

we have used radar measurements of a rice field. Although rice differs somewhat from the vegetation in natural wetlands, this approach has the advantage of eliminating many sources of uncertainty, such as variability in species mix, water content, and surface water. All the vegetation plots studied here consisted only of rice at the same seasonal stage, and all plots were flooded. In the next section we describe the characteristics of the rice field in detail. This is followed by an analysis of the observed radar characteristics of the various plots of rice. Finally, we discuss modeling of the observed response. We present a simplified model to describe the radar return as a function of LAI. This model is then inverted to retrieve the canopy attenuation.

2 Site Description and Data Acquisition

The data were acquired over a rice field in central California near the town of Colusa in July 1991, using the NASA/JPL DC-8 AIRSAR. This is a P-, L-, and C-band airborne synthetic aperture radar which is fully polarimetric [8]. Because of severe interference at P-band, only L-band and C-band data are used in this study. Several corner reflectors were deployed around the area and these were used in verifying the absolute calibration.

The area consisted of 23 rice plots which were imaged at 50° incidence angle. At each plot the water depth, plant height, number of stems per area, and LAI were measured. LAI was measured by cutting stems and measuring the area of each sample. All plots were flooded, with the water depth generally exceeding 10 cm. All rice had been planted at essentially the same time and was therefore at roughly the same stage. All plants extended 50 cm or greater above the water surface and were quite green, indicating a high water content. Figure 1 shows a scatter plot of the LAI versus plant height and Figure 2 shows LAI versus number of stems per unit area. These two figures show that the variation in LAI among the plots was due primarily to differences in the number of stems rather than to differences in the size of the plants. This is to be expected since all plots were planted at roughly the same time. This is a key point in our interpretation of the radar response, and we note that a time series of radar observations of a single plot over a growing season could potentially produce different results from those presented below. This is because the variation in LAI as a function of time for a single plot would be caused primarily by an increase in the size of the plants, while the number of stems per area would probably not change significantly. Because of the extensive labor required, detailed measurements of the rice stem size and orientation distributions were not possible. However, a visual inspection showed that the stems were predominately vertical and all appeared to be of similar size.

3 Radar Response to LAI Variations

Figures 3-6 are scatter plots of the radar cross sections versus LAI. At L-band both cross sections appear to increase slightly with increasing LAI, although the spread in cross sections at any particular LAI is quite large, typically 15 dB. At C-band, the HH cross section appears to decrease slightly, while the VV cross section decreases substantially as the LAI increases. The spread in cross sections at a particular LAI is much less at C-band than at L-band, typically being around 4 dB rather than 15 dB. We also examined the HV cross section, the HH-VV correlation coefficient, and the HH-VV phase difference at both L- and C-bands. Of these 6 parameters, only the C-band correlation coefficient shows dependence on LAI, decreasing from around 0.3 at low LAI to 0.1 at high LAI. The HH-VV phase difference does not depend on LAI. It has a very large spread, varying between 60° and 150° at L-band and between 0° and 80° at C-band.

4 Modeling the Radar Response

We model the rice field as a single layer of discrete scatterers over a reflecting surface, and use the Distorted Born Approximation [9],[10],[11]. The water surface is assumed to be flat so that there is no backscattering from it. In other situations, it is necessary that the surface backscatter be included, as done by Bouman [5] for X-band scattering from wheat in rough soil. For rice the scattered field with A -polarization (E^{AB}) for a B -polarized incident field, consists of direct (d), direct-reflected (dr), and reflected (r) components (see Figure 7):

$$E^{AB} = E_d^{AB} + E_{dr}^{AB} + E_r^{AB} \quad (1)$$

where the polarizations A and B can take on the values H or V . Note that in the literature the direct-reflected component is also referred to as the double bounce component. The direct reflected term itself consists of two components, the first being due to the incident wave penetrating the canopy, reflecting from the surface, and being forward scattered to the radar. The second component is due to a wave traveling the opposite path. As shown in [10] the two components add coherently. Assuming a single particle within the medium, having a scattering matrix S , the scattered fields are:

$$E_d^{AB} = S_d^{AB} \exp(i(K_A + K_B)t) \quad (2)$$

$$E_{dr}^{AB} = S_{dr}^{AB} (R_A + R_B) \exp(i(K_A + K_B)T) \quad (3)$$

$$E_r^{AB} = S_d^{AB} R_A R_B \exp(i(K_A + K_B)(2T - t)) \quad (4)$$

where R is a Fresnel reflection coefficient, T is the total distance the wave travels from the top of the medium to the surface and t is the distance traveled by the wave from the top of the medium to the particle. K_A is the propagation constant given by the optical theorem as $2\pi n_o \langle S_A(o) \rangle$, where $S(0)$ is the scattering matrix in the forward direction and the angle brackets denote averaging over all scatterer sizes and orientations; n_o is the number of scatterers per unit volume. Note that these represent spherical waves; the $\exp(ikr)/r$ factor is implicit. Also note that we have made an approximation in the direct reflected term that each polarization travels a distance T [11]. For like polarization this is exact. We are interested in finding the averages of the second order statistics of the fields, i.e., $\langle E^{AB} E^{CD*} \rangle$, where $A, B, C, D = H, V$. To do this we form products from (2)-(4) and then integrate over the depth of the medium, since the particle location is assumed to be a uniformly distributed random variable over the thickness h of the medium. Carrying out these operations yields:

$$\langle E_d^{AB} E_d^{CD*} \rangle = \langle S_d^{AB} S_d^{CD*} \rangle (1 - \exp(-ah/\cos\theta)) / (ah/\cos\theta) \quad (5)$$

$$\langle E_{dr}^{AB} E_{dr}^{CD*} \rangle = \langle S_{dr}^{AB} S_{dr}^{CD*} \rangle (R_A + R_B)(R_C^* + R_D^*) \exp(-ah/\cos\theta) \quad (6)$$

$$\langle E_r^{AB} E_r^{CD*} \rangle = \langle S_d^{AB} S_d^{CD*} \rangle R_A R_B R_C^* R_D^* (\exp(-ah/\cos\theta) - \exp(-2ah/\cos\theta)) / (ah/\cos\theta) \quad (7)$$

where $a \equiv -i(K_A + K_B - K_C^* - K_D^*)$ and θ is the incidence angle measured from nadir. These expressions can be converted to cross sections when $A = C$ and $B = D$ by multiplying by $4\pi n_o h$. It can be seen from (7) that the reflected term should be much lower than the direct term because of the two reflections and the two passages through the attenuating canopy. Hence, to simplify the model, we consider only the direct and direct reflected terms.

Given all of the parameters describing the rice canopy, these equations allow the radar measured parameters to be calculated. Application of these equations requires accurate measurements of the statistics of the rice plants. This would include the rice blade size and orientation probability density functions and the rice dielectric constants. Experimentation with the above model showed that the calculated radar parameters are quite sensitive to the size and orientation distributions. Since we do not have accurate measurements of the rice size and orientation distributions and dielectric constants, we further simplify the model. For the like polarization case the model can be written as

$$\sigma^o = \eta_d \cos\theta (1 - \exp(-2\alpha h/\cos\theta)) / 2\alpha + \eta_{dr} \cos\theta h |R|^2 \exp(-2\alpha h/\cos\theta) \quad (8)$$

where η is the cross section per unit volume and α is the attenuation coefficient. Rather than compute these coefficients, we will assume simple forms for them based on physical considerations. As was pointed out in section 2, the primary reason that the LAI varies in our data is a variation in the number

of stems between plots. Since LAI, η , and α are all proportional to n_o , we assume that both η and α are proportional to LAI. Using these assumed dependences:

$$\sigma^\circ = \cos \theta (1 - \exp(-2c_2 \text{LAI} / \cos \theta)) c_1 / 2c_2 + c_3 |R|^2 \text{LAI} \cos \theta \exp(-2c_2 \text{LAI} / \cos \theta) \quad (9)$$

and $\eta_d = c_1 \text{LAI} / h$, $\eta_{dr} = c_3 \text{LAI} / h$, and $\alpha = c_2 \text{LAI} / h$. Note that if we were trying to model the time dependence of radar return from a single rice plot, this model would not be appropriate. The LAI variation would be related to changes in leaf size rather than number density. Since LAI is proportional to leaf area but η and α are not, a different model would be needed.

5 Discussion

The model described in the previous section was fit to the HH and VV cross section measurements using nonlinear least-squares. The fit was performed using the cross section expressed in dB so that large and small cross sections were weighted equally, and Table 1 shows the resulting model coefficients. In all cases, the coefficient c_1 is zero, so the model fit indicates that scattering is dominated by the double-bounce return, and the volume scattering contribution is zero. The c_2 coefficient is zero at L-band, implying that the L-band attenuation is very small. The c_2 coefficients for C-band are non-zero, implying a higher attenuation at C-band than at L-band, as would be expected. The retrieved one-way path attenuation at the 50° incidence angle versus LAI is shown in Figure 8 for C-band. The V polarization attenuation is larger than that for H polarization, because of the vertical orientation of the rice blades.

6 Conclusions

In summary, we have observed that the radar return from a flooded rice field does show dependence on LAI, primarily in the form of a decreasing cross section with LAI at C-band, VV polarization. We derived a simple model for this data and then further simplified it by assuming that LAI variations are due to number density variations only. This model was fit to the observed HH and VV σ° data, and we found that double bounce scattering dominated at all LAIs. The model fit was used to retrieve the canopy path attenuation as a function of LAI. The C-band VV polarization sensitivity found here to LAI indicates that radar may indeed be a useful tool in remote sensing of wetlands.

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Figure Captions

Figure 1. Scatter plot of LAI versus plantheight.

Figure 2. Scatter plot of LAI versus number of stems per area.

Figure 3. Scatter plot of L-band VV radar cross section versus LAI.

Figure 4. Scatter plot of L-band HH radar cross section versus LAI.

Figure 5. Scatter plot of C-band VV radar cross section versus LAI.

Figure 6. Scatter plot of C-band HH radar cross section versus LAI.

Figure 7. Possible rice field scattering mechanisms.

Figure 8. One-way canopy path attenuation at 50° incidence angle, as retrieved by nonlinear least squares fit of model to data.

Table 1. Coefficients Resulting from Model Fit.

	c_1	c_2	c_3	RMS ERROR (dB)
LVV	0.0	0.0	0.1	4.4
LHH	0.0	0.0	0.1	5.1
CVV	0.0	0.2	1.4	2.1
CHH	0.0	0.1	1.4	0.7









