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ACTIVE MICROWAVE PROPERITES OF VEGETATION CANOPIES

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Justification. Potential users of radar imagery need a better fundamental understanding of the capabilities of radar systems for vegetation studies than past studies provide. One approach is the use of theoretical models to predict observable active microwave properties of vegetation. This in turn requires accurate observations of backscattering coefficients and other active microwave properties in field research studies. The background document for the SRAEC program emphasizes the need to relate electromagnetic parameters to classical biophysical descriptors and to understand the role of polarization, especially cross-polarization. Goals. The broad goal of my study is to increase the understanding of the effects of canopy structure on the active micorwave properties of vegetation canopies, with particular attention to polarization.

Approach. In the first year, I studied aircraft radar scatterometer measurements of corn and soybean fields in Iowa to determine the properties of these mature fields at L-band (19 cm) and C-band (6 cm) and at sensor look-angles from 5 to 50 degress. In the second year, I used the Cloud Model (Ref. 1) with a set of X-band (3 cm) and K-band (2 cm) truck-based radar like-polarization data for corn in Kansas to extend the model and to relate the model parameters to biophysical characteristics of the corn. For the third and current year, I used a C-band dual-polarization truck scatterometer at the University of California Kearney Agricultural Center to measure the active microwave properties of trees in orchards. Using the Cloud Model, I was able to estimate not only the backscattering coefficient, but also the attenuation coefficient, the density of backscattering cross sections, and the transmittance. The research activity lead to a new procedure in using such truck-based radar scatterometer data for thick, volume scattering media.

Results.

First Year. In the first year, I found that mature corn and soybean fields could be best separated with the use of C-band cross-polarization (HV) data at 50 degrees. No separation existed for C-band like-polarization (HH). At L-band, the separation of corn and soybeans was best for like-polarization (HH), but was not as good as it was for C-band HV data. No separation existed in L-band cross-polarization data. I observed significant row direction effects for sensor look-angle near 15 degrees when like-polarization was used. These effects were strongest at L-band. No row direction effects existed for cross-polarization for either band. Finally, I observed that the presence of wet soil and/or wet canopy due to rain reduced the separations of corn and soybeans and produced a significant increase in backscatter, especially near 15 degrees.

Second Year. In examining the Cloud Model, I found that the model form was significantly different for cross-polarization than it was for its usual like-polarization formulation. Also, I found that the use of the ratios of backscattering coefficients for the various polarization combinations (VV, HH, HV and VH) could lead to the isolation of canopy angular orientation properties.

This allowed a new interpretation of the corn and soybean data studied in the first year. Similar separations existed in the depolarization ratio (cross-polarization divided by like-polarization) such as existed independently in the better of the two channels. Finally, by applying the Cloud Model to through-the-season, truck-based radar scatterometer measurements, I could estimate the backscattering and extinction cross sections of average leaves. I found that the former was a simple power-law function of corn leaf area (r^2 of 0.97) throughout the season.

Third Year. I used the Microwave Scatterometer C-band (MSC), on loan from the NASA Johnson Space Center, mounted on a JPL truck (height of 11 m) to make field measurements. This instrument obtains calibrated radar backscattering coefficient data in the field. However, it samples a volume that is limited in size due to the finite range-resolution and the finite beam-width. It obtains data at both like-polarization and cross-polarization. Through the use of the ranging capability of the MSC and the Cloud Model, I was able to estimate the active microwave properties of vegetation canopies, as follows: (1) the true, corrected backscattering coefficient, ${S^o}_T$; (2) the volume extinction coefficient K (m^{-1}); (3) the backscattering cross section density, Σ (m^2 m^{-3}); (4) the two-way transmittance of the canopy, t_i t_j (i and j stand for H or V to denote the polarization combination used); (5) the "full canopy" backscattering coefficient, ${S^o}_{FC}$; and (6) the distribution of sources with range. For a given vegetation canopy these active microwave characteristics vary with polarization or polarization combination.

Illustration of the New Procedure. The procedure to obtain these parameters is illustrated below for an ideal case where the canopy properties are homogeneous. One view of the Cloud Model is that the observed backscattering coefficient is given by

$$S^o = \int_{R_1}^{R_3} f \, dR = \int_{R_1}^{R_2} f_1 \, dR + \int_{R_2}^{R_3} f_2 \, dR \qquad (1)$$

for the one-layer case, where the canopy elements are found between the ranges, R_1 and R_2 (m), with the reflected (mirror image) canopy extending to range R_3 (m),

$$f_1 = E_{ij} \cos (T) \exp [-(K_i + K_j) (R - R_1)] \qquad (2)$$

$$f_2 = E_{ij} \, r_{ij} \cos (T) \exp [-(K_i + K_j) (R_2 - R_1)] \cdot \exp [-(K_i + K_j) (R - R_2)] \qquad (3)$$

where T is the sensor look-angle (degrees), r_{ij} is the surface reflectance (assumed to specular in basic character) for polarization ij, and R is the range (m).

The integration of Eq. (1) over the entire range from R_1 to R_3 with the expressions in (2) and (3) leads to the true canopy backscattering coefficient,

$$S^o{}_T = E_{ij} \cos (T) (1 + r_{ij} t_i t_j) (1 - t_i t_j) + t_i t_j S^o{}_{ijs} \tag{4}$$

where $S^o{}_{ijs}$ is the surface backscattering coefficient.

However, for the MSC (or any scatterometer having a small, finite range resolution), the sensor measures only a fraction of the total backscattering. I call this the partial backscattering coefficient (measured) which is related to the function f by

$$\Delta S^o = \int f \, dR \text{ (over the range resolution, } \Delta R) \tag{5}$$

Since ΔR is small it is possible to estimate the function f by $\Delta S^o/\Delta R$.

Figure 1 shows the comparison between the given (true) value of f and the estimated value of f as obtained from a modeled prediction of the "measured" partial backscattering coefficient (see Figure 2). The estimated f is close to the given f for some ranges but not for all ranges. Now, it is possible to perform a numerical integration to estimate the true value of backscattering coefficient as indicated in Eq. (1) above. For thick vegetation canopies, the true value is significantly higher than the largest partial value. Thus, this procedure is required for such situations.

Since the variation of f with range is a decaying exponential function, the use of the logarithm of f (or alternatively, expression of f in deciBels, dB) leads to a straight line portion of the f (dB) versus R curve (see Figure 3). Passing a straight line through points in this segment allows estimation of both E and K by

$$E = f_{R_1} \sec (T) \quad \text{and} \quad K = \text{slope}/(-8.686) \qquad \text{(6) and (7)}$$

With the estimated value of K and the known slant range thickness of the canopy, t_i t_j can be estimated. Using rough estimates of r and surface backscattering coefficient, one can estimate independently the value for E. This value should be close to that estimated for Eq. (6). With the new values for E and K it is possible to estimate the "full canopy" backscattering coefficient from

$$S^o{}_{FC} = E \cos (T)/(K_i = K_j) \tag{8}$$

If the second (reflected) portion of the f (dB) versus R curve can be detected, it is possible to extrapolate the two straight lines (one from ranges less than the range to the surface, and one for ranges greater than the range to the surface) to the surface range values of f_L (left side) and f_R (right side) and calculate r by f_R/f_L. Since the estimated value of f at R_2 may be higher than the average value of f_L and f_R due to the contribution of attentuated surface backscattering, it is possible to estimate the surface backscattering coefficient.

Results with Orchards. Figure 4 shows the partial backscattering coefficients versus range for a young peach orchard (see Figure 5 which indicates the tree structure). Note that near the top of the canopy the radar return is dominated by the VV where HH dominates the return near the base of the canopy. After the noise floor is estimated and subtracted, the data were used to estimate f (dB) as shown in Figure 6. The active radar parameters shown in Table 1 are obtained from these data using the above procedure.

Significance of Results. The three year study shows that, in many cases, cross-polarization or a combination of HH, VV and/or cross-polarization yeilds information on the angular orientation of vegetation canopies. Ratios of channels should be used to isolate such information from other vegetation characteristics such as total areal biomass or water content. Furthermore, with the proper use of simple microwave scattering models, such as the Cloud Model, and accurate radar scatterometer data, it is possible to esitmate the total backscattering coefficient, the attentuation coefficient, the transmittance, and average scattering and extinction radar cross sections of scattering elements. These data should prove useful for verification of modeling approaches and for the development of adequate understanding of the information content of radar sensor data such as from the synthetic aperture radar (SAR) imagers.

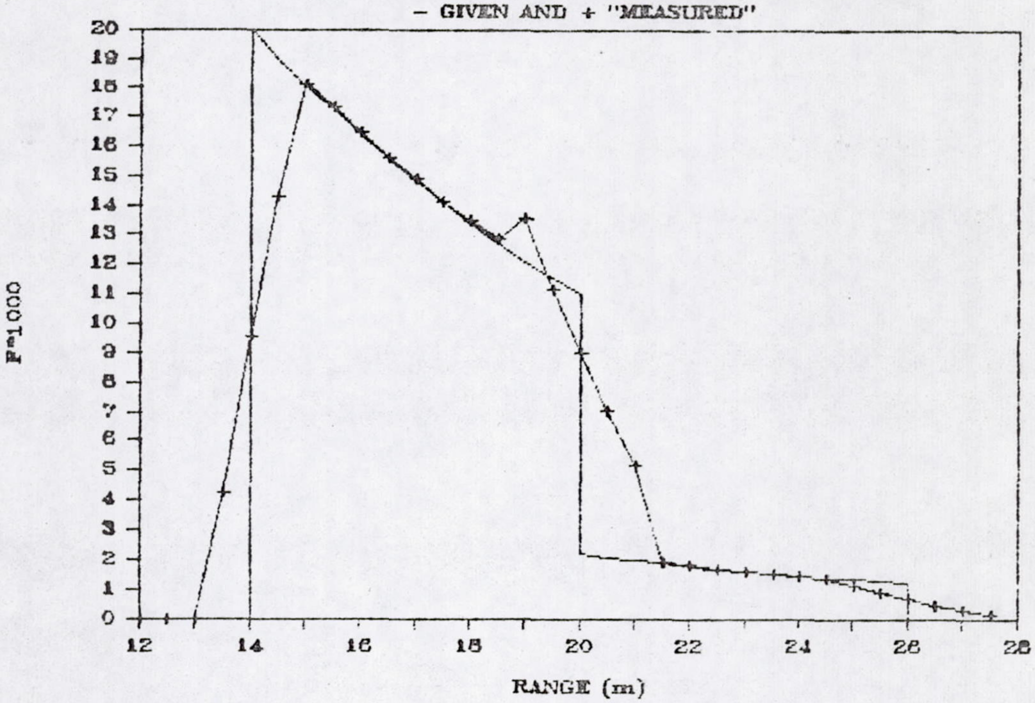
Cited References.

1. Attema, E.P.W. and F.T. Ulaby, 1978: Vegetation modeled as a water cloud. Radio Sci. 13(2):357-364.

Table 1.

Example of Measured Active Microwave Properties of Orchards Through Analysis of Truck Radar Scatterometer Measurements at C-Band and 60 Degrees

Field	Pol	ΔS^o_{max}	S^o_T (dB)	E (m^{-1})	K (m^{-1})	t_2	S^o_{FC} (dB)
Mature	VV		-10.2	0.077	0.199	0.021	-10.1
Peach	HH		-11.6	0.050	0.178	0.031	-11.5
Orchard	VH		-17.3	0.014	0.188	0.026	-17.2
Young	VV		-10.4	0.036	0.082	0.203	- 9.6
Peach	HH		-12.1	0.028	0.087	0.286	-11.0
Orchard	VH		-15.8	0.011	0.084	0.241	-15.1



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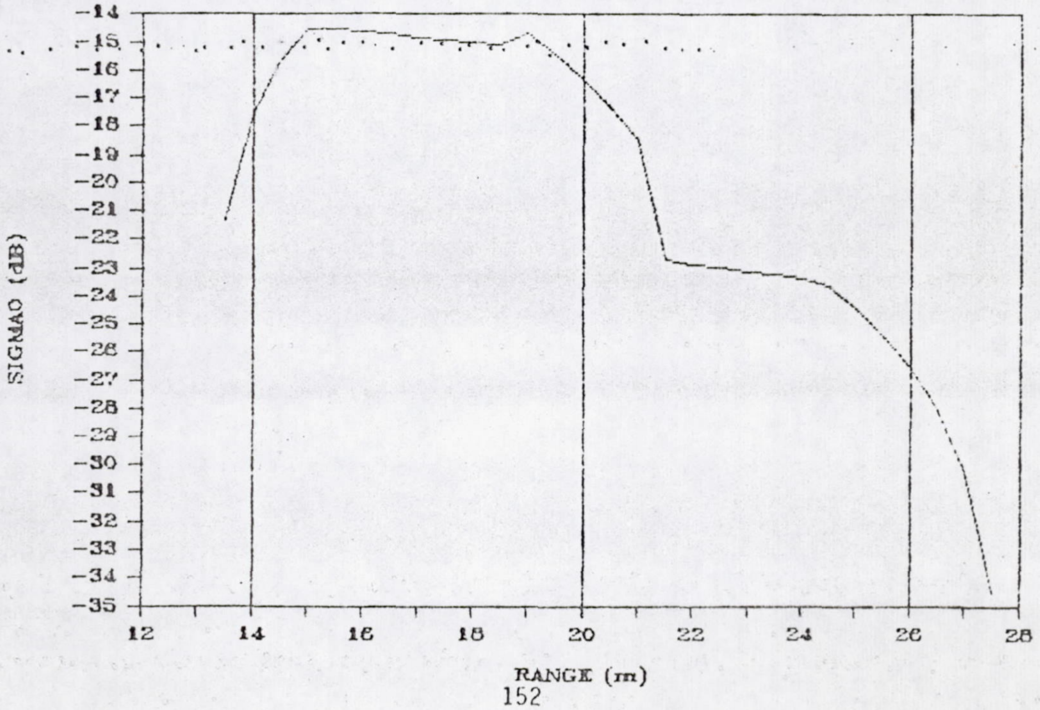

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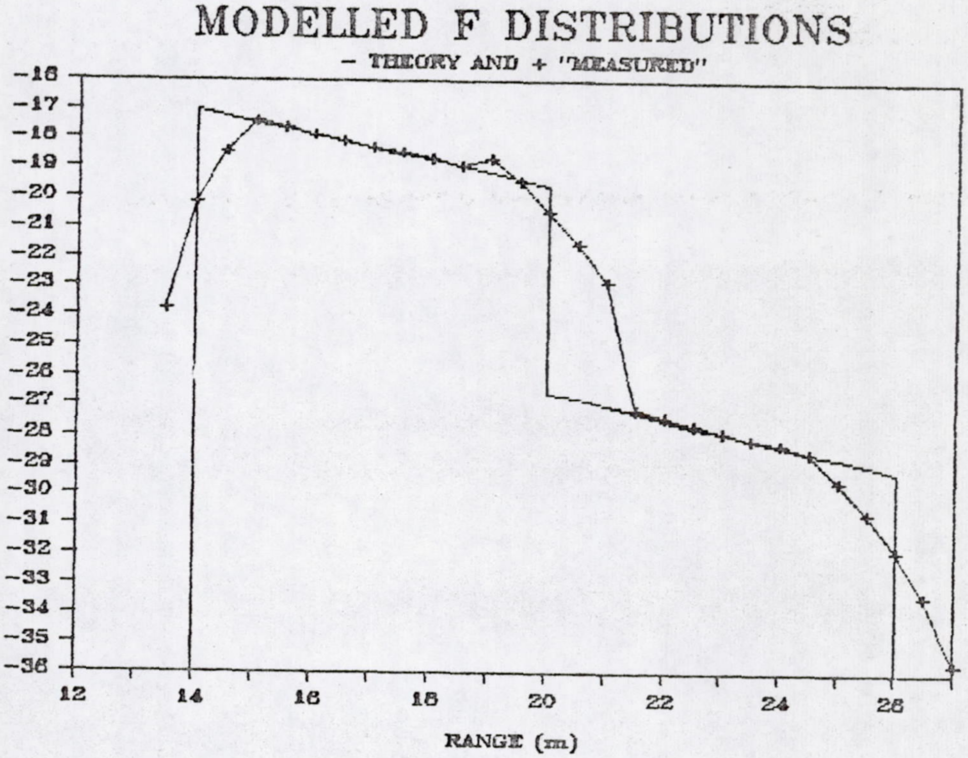

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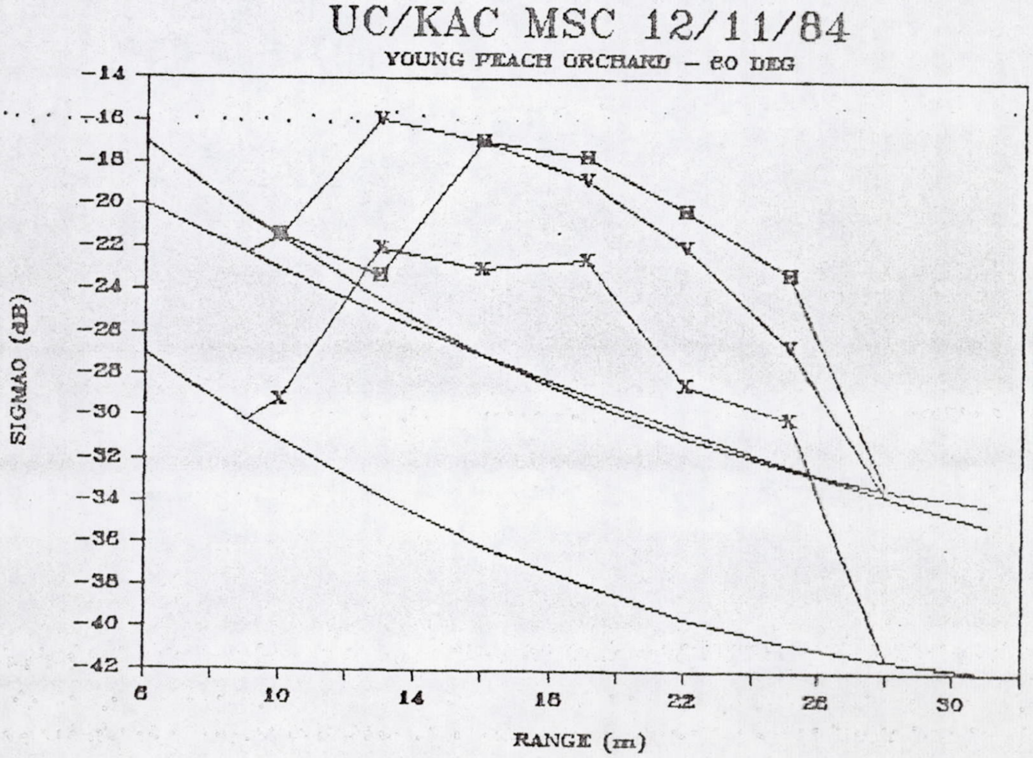

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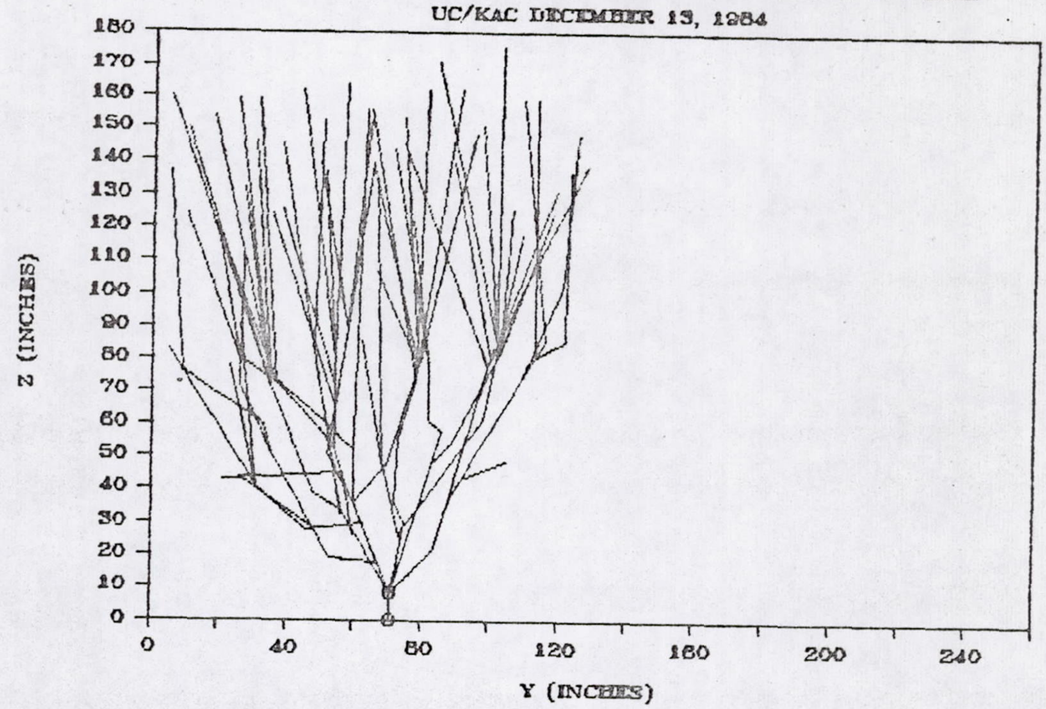
YOUNG PEACH ORCHARD – 60 DEG



YOUNG PEACH TREE STRUCTURE

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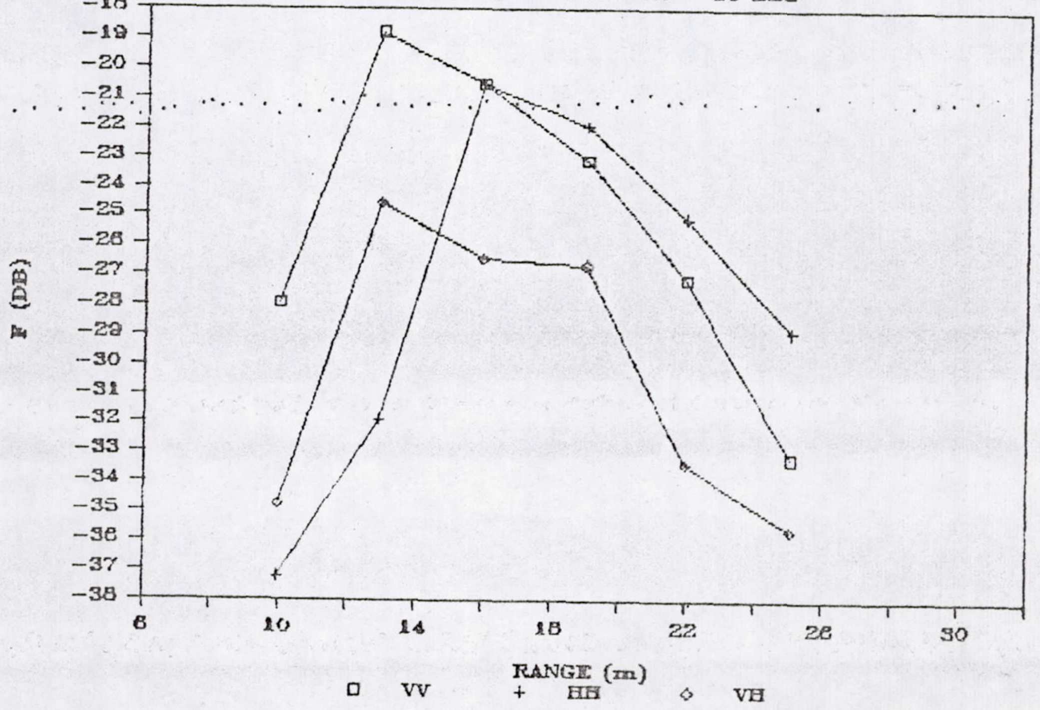

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YOUNG PEACH ORCHARD – 60 DEG