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MICROWAVE DIELECTRIC AND PROPAGATION PROPERTIES OF VEGETATION CANOPIES

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A vegetation canopy is a highly inhomogeneous medium at microwave frequencies, and because the scattering elements (leaves, stalks, fruits, and branches) have a nonuniform distribution in orientation, the canopy is likely to exhibit nonisotropic attenuation properties. In some canopies, the stalk may contain the overwhelming majority of the plant's biomass, which suggests that an incident radar wave would be differentially attenuated by the canopy depending on the direction of the incident electric field relative to the stalks' orientation. The propagation properties of a vegetation canopy play a central role in modeling both the backscattering behavior observed by an imaging radar and the emission observed by a radiometer. These propagation properties are in turn governed by the dielectric properties and the size, shape, and slopedistributions of the scatterers. In spite of the critical need for canopy propagation models and experimental data, very few investigations had been conducted (prior to this study) to determine the extinction properties of vegetation canopies, either by constituent type (leaves, stalks, etc.) or as a whole.

A three-faceted approach was undertaken in this study consisting of complimentary investigations with each providing answers to specific aspects of the overall question. The first facet consisted of dielectric measurements that were conducted over the 1-10 GHz band to determine the variations of the dielectric permittivity and loss factor as a function of water content and salinity. Dielectric mixing models were developed and evaluated against the experimental data for individual plant parts (leaves, stalks, fruit) of several types of plants (wheat, corn, and soybeans). An example is shown in Fig. 1.

The second facet of the study consisted of direct measurements of canopy attenuation. Using truck-mounted radars as transmitting sources positioned above the canopy, and small receive antennas mounted on fiberglass rails underneath the canopy (on the soil surface), attenuation measurements were conducted as a function of incidence angle (relative to nadir), microwave frequency, and polarization configuration. In addition, special experiments were conducted to evaluate the relative contributions of the various canopy constituents to the total loss (or attenuation) factor of the canopy. These included wheat decapitation experiments, in which measurements of the canopy loss factor were made before and after cutting off and removing the wheat heads, and soybean defoliation experiments which provided comparison of the extinction loss due to the stalks alone with the total loss due to the stalks and leaves together. According to Fig. 2, the stalks account for the majority of the propagation loss in a soybeans canopy for vertically polarized waves, whereas the leaves are the dominant absorbers for horizontal polarization.

A canopy propagation model was developed consisting of three terms: (a) leaf term that accounts for absorption by randomly oriented disc-shaped leaves, (b) a stalk term that accounts for absorption by a uniaxial crystal consisting of thin, vertical, lossy cylinders in an air background, and (c) a branch term that accounts for the loss by a medium containing randomly oriented needle-shaped branches. The first and third terms are polarization-independent and vary with incidence angle as sec θ. The stalk term has a strong dependence on both polarization and incidence angle. The model was found to be in good agreement with experimental observations. One of the key parameters in the model is the dielectric constant of the vegetation material, which was calculated using the dielectric mixing models developed in the first facet of this investigation. The combination of the dielectric mixing model and the canopy propagation model provides the means to compute the loss factor of the canopy if given the water contents and volume fractions of the canopy constituents and the canopy height. The model accounts for the dependence on incidence angle, polarization and wavelength.

In the next facet of this study, we attempted to relate the results obtained above to the remote sensing problem. In order to focus the study on the canopy itself and avoid problems associated with variations in the soil background, it was decided to cover the soil surface with screen wire and make passive microwave observations as a function of time over the growing cycle. The screen wire, while it has no discernible effect on the growth of the plants, acts as a conducting surface with a near-zero emissivity. Thus, soil moisture variations exercise no influence on the canopy emission. This technique was used to investigate the variation of the brightness temperature of the canopy with look direction (relative to the row direction), incidence angle, and polarization configuration for wheat, soybeans, and corn canopies. A radiative transfer model was used to relate the brightness temperature to biophysical parameters of the canopy through the canopy loss factor. Figure 3 shows that the experimental observations are in good agreement with the model predictions. A second set of radiometer observations were made for canopies under natural conditions (no screen used). The radiative transfer model was extended to include a soil-moisture term that accounts for the emission and reflection by the soil surface. Again good agreement was found between theory and experiment.

The majority of microwave scattering and emission models reported in the literature have treated the canopy as an isotropic medium. This implies that the attenuation coefficient is independent of polarization, incidence angle, and look direction (in azimuth). The present study has shown that in most cases, none of the above assumptions are valid. Consequently, modelers will have to incorporate the anisotropic character of the canopy in their models, which is likely to lead to more applicable models for the backscattering and emission from vegetation than now exists.

The work conducted to data has established the overall functional relations between the propagation coefficients of a vegetation canopy and its biophysical and geometrical properties. The results, however, are based on a number of specific experiments that were conducted for a specific set of crops at specific stages of growth. The goal of the next phase of this study is to develop a general propagation model that may be applied to a wide range of canopy types and conditions. The experimental component of the study will be designed accordingly.

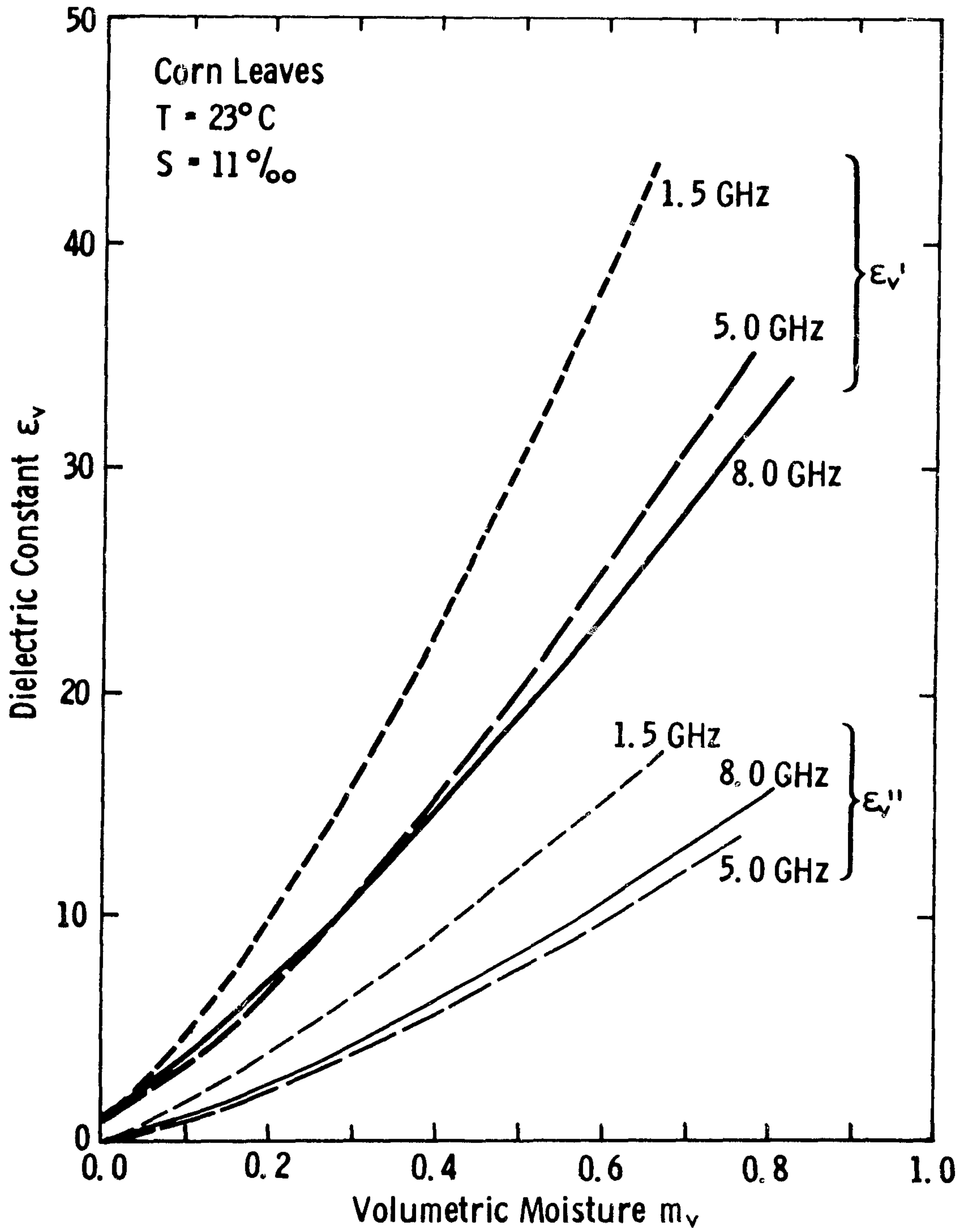
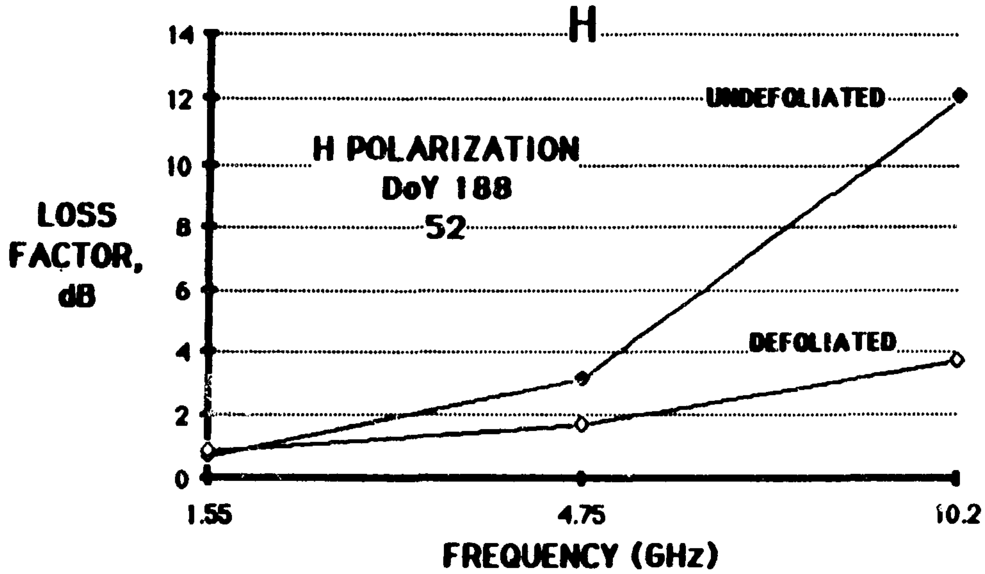


Figure 1. Measured Dielectric Behavior of corn leaves.



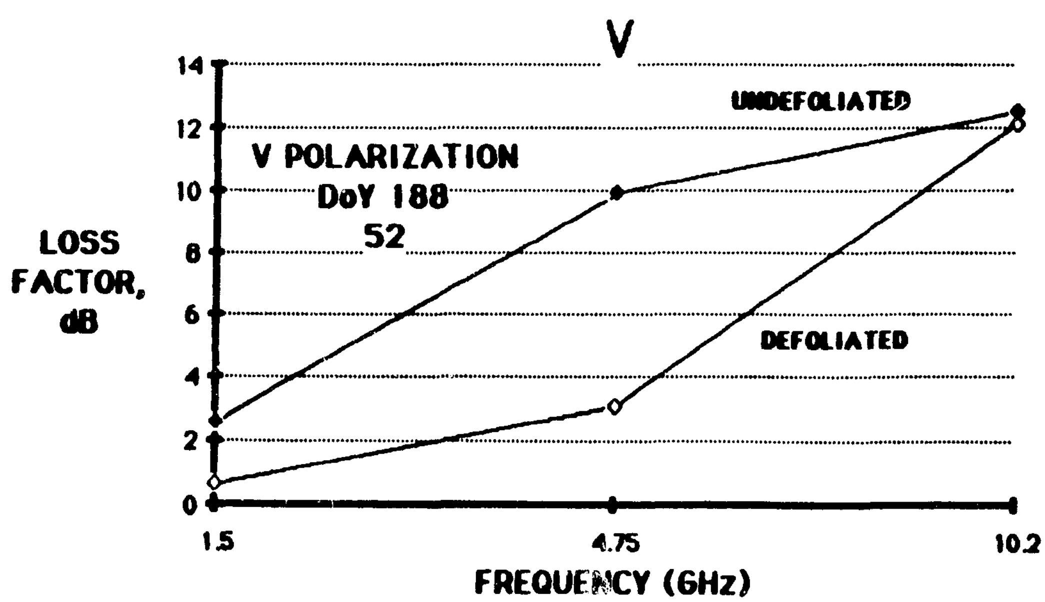


Figure 2. Comparison of attenuation measurements made for soybeans canopy before and after defoliation for vertical and horizontal polarizations.

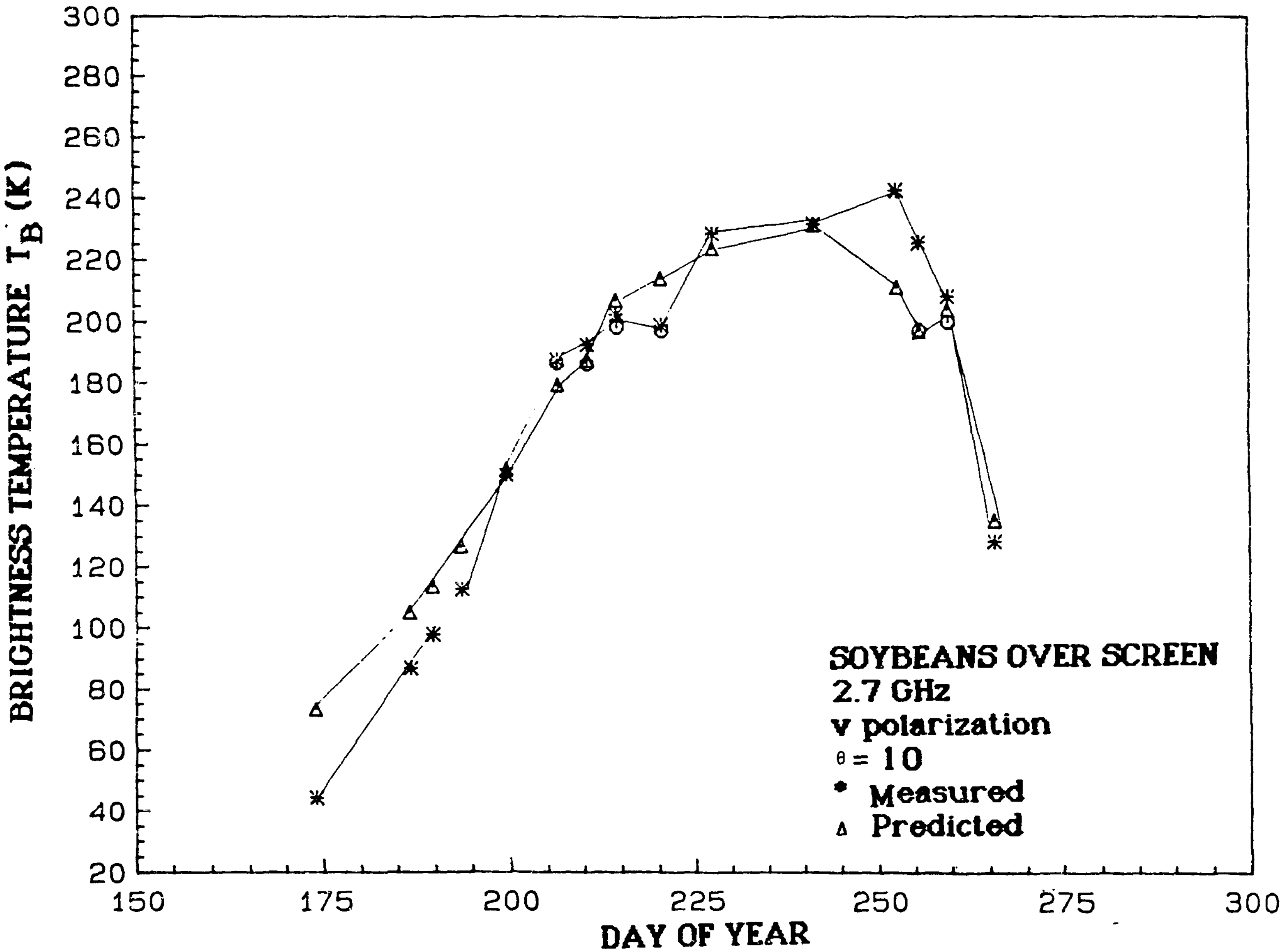


Figure 3. Comparison of the temporal record of the brightness temperature of soybeans canopy with model prediction.