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DETERMINATION OF BACKSCATTERING SOURCES IN VARIOUS TARGETS

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OBJECTIVES

The objectives of this research are to identify the primary contributors to 10-GHz radar backscatter from various natural and man-made surfaces and objects, and to use this information in developing new and better models for the scatter. When the true sources are known for the scattering that leads to variation in intensity on radar images, the images (and sets of them) may be interpreted more meaningfully in terms of the variation of parameters of interest for science or application. For example, better interpretation of vegetation images may be possible for yield forecasting and stress detection.

APPROACH

Backscattering coefficient (σ^o) measurements from crops, soil, snow, etc. have been conducted for over three decades, but only a minimal effort has been focused on determining the sources of backscattering in those targets. Using a pulse radar, Graf and Rode [1982] in Germany used a solitary fir tree to determine its major sources of backscattering. Ulaby et al. [1982], using a defoliation technique, conducted scattering measurements on several types of crops. The only previously reported extensive direct measurements of sources of scatter have been conducted by the Remote Sensing Laboratory at the University of Kansas through this research in 1983 [Zoughi et al., 1985; Wu et al., 1985]. The approach and the results of these experiments provided the primary guidelines for the 1984 experiments.

To measure the relative backscattered energy from various constituents in a target (i.e., corn cob, stalk, leaves), a radar system with a fine range resolution and a small footprint at the target range is required. Measurements conducted during 1983 utilized an available FM-CW radar system adapted so that its transmitted frequency swept over a wide band to produce a range resolution of about 11.0 cm. A focused parabolic-reflector antenna system was used to provide narrow beamwidths in both the azimuth and the elevation directions; this resulted in a footprint of 15 x 18 cm at the range of 4 m. Associated with this system were relatively high range-sidelobe levels which made target detection ambiguous at times. Therefore, funding for a specialized radar system was requested and approved. Consequently, a short-range very-fine resolution FM-CW radar system was designed and built. This radar system (SOURCESCAT) also provides a range resolution of 11 cm, but its range-sidelobe levels are appreciably reduced. The same focused antenna system used in 1983 was used with the SOURCESCAT.

Targets examined during the 1984 growing season included corn, soybeans, wheat, alfalfa, short grass, tall prairie bluegrass and several types of trees. To determine the main sources of backscattering in these targets, constituent defoliation (i.e., for corn and trees) and layer-by-layer defoliation (i.e., soybeans and tall grass) were implemented. All the measurements were conducted at incidence angles of 30° and 50°.

RESULTS

For an individual corn plant, backscattered energy is mainly due to the leaves; scattering from the cobs and the stalk is negligible, as shown in Figure 1. For a canopy, echoes from the upper 1 - 1.5 m portion of the plants dominate the total echo. Energy returned from the ground is insignificant due to the two-way attenuation of the radar signal through the canopy.

Soybeans are very lossy volume scatterers. The two-way loss through one row of plants ranges from 20 to 15 dB at 30° and 50°, respectively. Backscattered energy from the upper 30 cm of the plant dominates the returned signal. The energy returned from this portion is about the same at both incidence angles. Layer-by-layer defoliation indicates that the unattenuated backscattering from various leaves in the canopy is about the same.

The backscatter from wheat is dominated by the heads in both the early and late stages of the growth. Backscatter from heads remains almost constant at different stages, but attenuation through the heads is considerably more at the early stages of growth due to its higher moisture content at this stage. This shows backscatter insensitivity to moisture content but direct loss due to moisture content of the heads.

Individual alfalfa plants of about 40 cm tall were observed with no defoliation performed. In the presence of the plants, the returns due to the entire plants dominated the radar signal (individual parts of the alfalfa plants are too small to resolve). The returns in this case were slightly higher at 30° than at 50° incidence angles. With the plants removed, backscatter from the roots was observed at the depth of 5 to 12.5 cm beneath the ground.

Two different tall prairie grasses (50 cm high) were examined. The first site was an undisturbed and natural site which contained the dead grass material from the previous year on top of the soil. The second site had this dead material intentionally burnt off the soil before the growing season. Therefore, the latter site contained less soil moisture than the former site. The results of our measurements were also in agreement with this fact. In both cases, a volume of grass about 15 cm thick and about 25 cm above the soil gave the strongest backscattered energy. This experiment was conducted in collaboration with investigators from Kansas State University.

For pine trees, the needles showed the strongest backscatter, and caused the strongest attenuation in the radar signal. Cones, although insignificant contributors to the total backscatter, exhibited more backscattering than attenuation properties. Figure 2 illustrates these results.

Four types of deciduous trees were examined. Leaves were a strong cause of backscattering and attenuation. However, removing the leaves and keeping the leaftails and small twigs and branches reduced the backscattered energy very little. Therefore, their contribution to the total backscatter cannot be ignored.

These results are in great agreement with the results of the 1983 experiments, but there is more confidence in these results because a greater number of independent samples were observed and the ambiguities caused by range sidelobes were much less.

DISCUSSION

To obtain a complete understanding of the wave-target interaction process, experiments need to be conducted and models developed in each of the following areas:

(1) Target Dielectric Properties: To model a vegetation canopy, the dielectric constant of canopy constituents (leaves. stalks, fruits, etc.) as a function of temperature and water-volume fraction needs to be known.

(2) Target Attenuation Properties: For media such as snow, forests, and vegetation canopies, attenuation properties of the medium are essential in modeling.

(3) Target Volume Geometry: Methods need to be developed to measure the three-dimensional statistical distribution of orientation and density of scatterers within the volume.

(4) Target Scattering Properties: Extensive measurements need to be conducted on the scattering behavior of (a) targets under natural conditions, and (b) target constituents.

Information from all of these four areas enter into a scattering model. The existing scattering models in many cases assume or estimate the contribution of some of these parameters to the whole model. To develop complete models, these assumptions and estimations must very closely coincide with the true state of these parameters. This can only be achieved through sound experiments in the above areas.

By modeling the scattering properties of target constituents and using our experiment results to cross-check the models, we may be able to model correctly the scattering properties of the target as a whole.

A method-of-moments solution is proposed to compute the scattering from the individual plant parts, which may be modeled as dielectric cylinders, ellipsoids or smooth-curved dielectric slabs of arbitrary shapes. The analysis is based on the LeVine-Schwinger integro-differential equation, derived from the equivalent polarization current. The solution for the total field is obtained numerically. The far-zone approximation is applied to the integral equation. Given the total field inside the dielectric scatterer, we can calculate the scattered field and, therefore, the scattering cross-section.

More concentrated experiments and research in this area are needed to answer all the related questions raised and those that may be introduced as the research progresses. Experiments on more natural targets and man-made targets (such as buildings) will continue in 1985, along with extensive efforts on developing scattering models.

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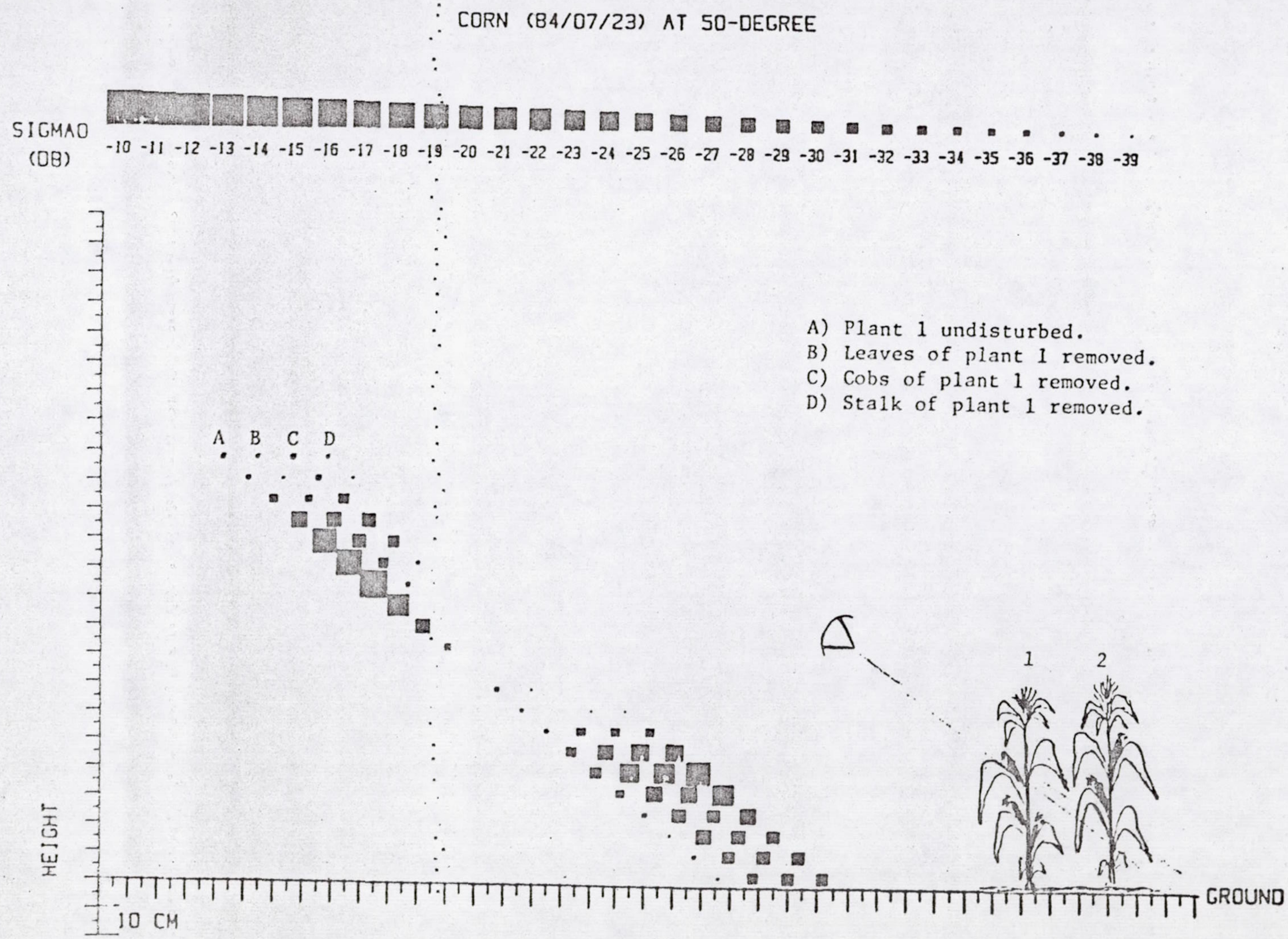
CORN (84/07/23) AT 50-DEGREE
SIGMAO
(DB)
-10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23 -24 -25 -26 -27 -28 -29 -30 -31 -32 -33 -34 -35 -36 -37 -38 -39
A) Plant 1 undisturbed.
B) Leaves of plant 1 removed.
C) Cobs of plant 1 removed.
D) Stalk of plant 1 removed.
A B C D
1
2
HEIGHT
10 CM
GROUND

Figure 1

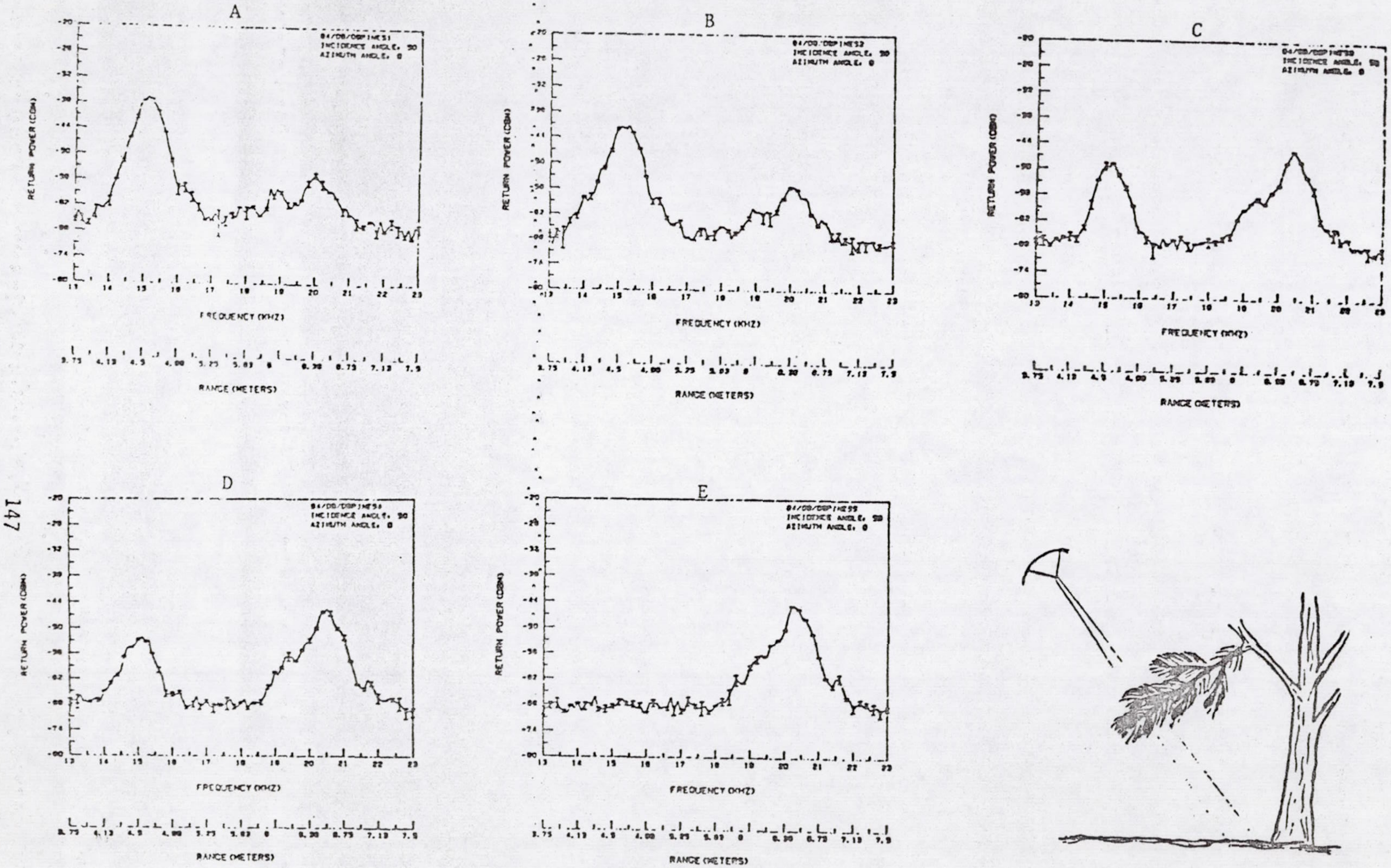

Figure 2: Pine Tree Results. First echo due to the branch, second echo due to the ground.
A) Undisturbed branch, B) Cones removed.
c) Pine needles removed, D) Small branches removed.
E) Main branch removed.