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CHARACTERIZATION OF VEGETATION BY MICROWAVE AND OPTICAL REMOTE SENSING

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INTRODUCTION

For more than two decades, scientists have studied separately the properties of vegetation in the optical and microwave regions of the electromagnetic spectrum. Each spectral region appears to contain unique information about vegetation. Measurements by optical sensors depend on the differential scattering and absorption caused by chlorophyll, leaf structure, green leaf area, leaf water content, and soil background (Bunnik, 1978; Knipling, 1970). Microwave sensors respond to larger scale structure of the canopy, plant water content, plant part size distributions, and soil surface conditions (Attema and Ulaby, 1978; Brumfeldt and Ulaby, 1984a).

However, most microwave research related to vegetation has focused only on species identification (Bush and Ulaby, 1978) or the effects of vegetation on the determination of soil moisture (Dobson et al., 1984;Dobson and Ulaby, 1986). Strong evidence suggests that the backscatter returns of active microwave systems are related to vegetation canopy density and structure (Allen and Ulaby, 1984; Brumfeldt and Ulaby, 1984b).

It is significant to note that the parameters affecting optical and microwave radiation appear to be complementary in that they represent different, but interrelated, aspects of the scene (Goel, 1985). Because the physical parameters affecting both optical and microwave radiation are related to the quantity and quality of phytomass, the opportunity exists to utilize remote sensors to obtain data that are needed to model the growth and net productivity of vegetation. These are key concerns for modeling global carbon cycles, as well as assessing the ability of ecosystems to support human life.

Relatively little remote sensing research has been devoted to assessing the quantity or vigor of vegetation. The key research issue is how to determine the important biophysical characteristics of diverse vegetative canopies using multispectral (optical and microwave) remote sensing.

The overall objective of this multi-year research project is to measure and analyze microwave and optical data, singly and in combination, for characterizing diverse vegetative canopies. The specific objectives of this research were:

1. Determine the relationships between backscatter and the biophysical characteristics of a broad range of canopy types.
2. Determine the feasibility of using simulated tree canopies for evaluating backscattering from forest scenes.
3. Implement and exercise backscattering models using data acquired by the C-Band microwave scatterometer.

Such information will be important to scientists in understanding the relationships between remotely sensed (microwave and/or optical) data and the biophysical characteristics of vegetation. The goals of the Space Station Earth Observing System make it imperative that these relationships be understood. This research will help establish a sound physical and biological basis for interpreting the radiation-absorbing and -scattering properties of vegetation.

EXPERIMENT DESIGN

Two series of carefully controlled experiments were conducted in 1984 and 1985. First, plots of important crops (corn, soybeans, and sorghum), prairie grasses (big bluestem, switchgrass, tall fescue, orchardgrass, bromegrass), and forage legumes (alfalfa, red clover, and crown vetch) were manipulated to produce wide ranges of phytomass, leaf area index, and canopy architecture. Second, coniferous forest canopies were simulated using small (1.3 m) balsam fir trees grown in large pots of soil and arranged systematically on a large (5 m) platform. Rotating the platform produced many 'new' canopies for frequency and spatial averaging of the backscatter signal. In both series of experiments, backscatter of 5.0 GHz (C-Band) was measured as a function of view angle (0 to 60 degrees in 10-degree increments) and polarization. Biophysical measurements included leaf area index, fresh and dry phytomass, water content of canopy elements, canopy height, and soil roughness and moisture content. For a subset of the above plots, additional measurements were acquired to exercise microwave backscatter models (Attema and Ulaby, 1978; Eom and Fung, 1984). These measurements included size and shape of leaves, stems, and fruit and the probability density function of leaf and stem angles. The dielectric properties of canopy components were measured by the Radiation Laboratory at the University of Michigan.

Optical data of these experiments were also acquired using the Barnes 12-1000 (TM bands) and Exotech 100 (MSS bands) radiometers. In future analyses, optical and microwave data will be combined. The relationships of the backscattering coefficients and the biophysical properties of the canopies were evaluated using statistical correlations, analysis of variance, and regression analysis. Results from the corn density and balsam fir experiments are discussed and analyses of data from the other experiments are summarized.

Corn Density Experiment

Four densities (2.5, 5.0, 10.0, and 15.0 plants/m^2) of corn (*Zea mays* L. 'Pioneer 3732') were planted in 0.76 m rows on 14

May and 4 June 1984 at the Purdue University Agronomy Farm. The second experiment was planted on 23 May 1985 and consisted of three densities (2.5, 5.0 and 10.0 plants/m^2) of corn (Pioneer 3732) in 0.76 m rows and three densities (5.0, 10.0, and 20.0 plants/m^2) of corn in 0.38 m rows. High levels of soil fertility were maintained by applying 250, 44, and 130 kg/ha of N, P, and K, respectively, as indicated by soil tests. The four densities of corn produced four distinct levels of fresh and dry phytomass and leaf area index throughout most of the growing season (Fig. 1). Plant water content (not shown) also differed significantly among the plant densities and was highly correlated to fresh phytomass. Plant height and stage of development were not significantly affected by plant density. As competition among the plants increased, the phytomass and leaf area per plant decreased and the number of barren plants (i.e., plants with no grain on their ears) increased.

The C-Band microwave scatterometer (MSC) was mounted on a mobile aerial tower (Hi-Ranger truck) and backscattering data were acquired as a function of polarization (HH, HV, VV) and view zenith angle (0 to 60 degrees in 10-degree increments). The backscatter coefficients measured parallel to the row direction decreased rapidly as the view zenith angle increased from 0 degrees (vertical) to 30 degrees (Fig. 2). Changes in backscatter were much smaller at view zenith angles greater than 30 degrees. Both like- (HH, VV) and cross- (HV) polarizations responded similarly to changes in view angle although the cross-polarization backscatter was approximately 5 dB lower than the like-polarization backscatter.

Selected relationships between the biophysical characteristics of corn and the backscatter coefficients at 30 degrees for HH polarization are shown in Figure 3. In general, as phytomass and leaf area index increased, the backscatter coefficients (in real units) also increased linearly. A portion of the scatter about the regression lines (Fig. 3) is undoubtedly associated with experimental error; however, each backscatter coefficient is the mean of at least 25 independent observations and each biophysical measurement is the mean of at least 10 plants per plot. Other sources of variations in the backscatter at 5.0 GHz are related to soil moisture content, soil texture (particle size distribution), and soil roughness (Dobson et al., 1984). In this experiment, soil texture was a silt loam and was uniform throughout all plots. Soil moisture and surface roughness changed during the season but were not significantly different among the plots on each measurement date.

Additional research is needed to carefully evaluate the effects of soil moisture and surface roughness on microwave backscatter coefficients of vegetation. It may be possible and profitable to use multiple view angles and polarizations to minimize the variation in microwave backscatter due to the soil

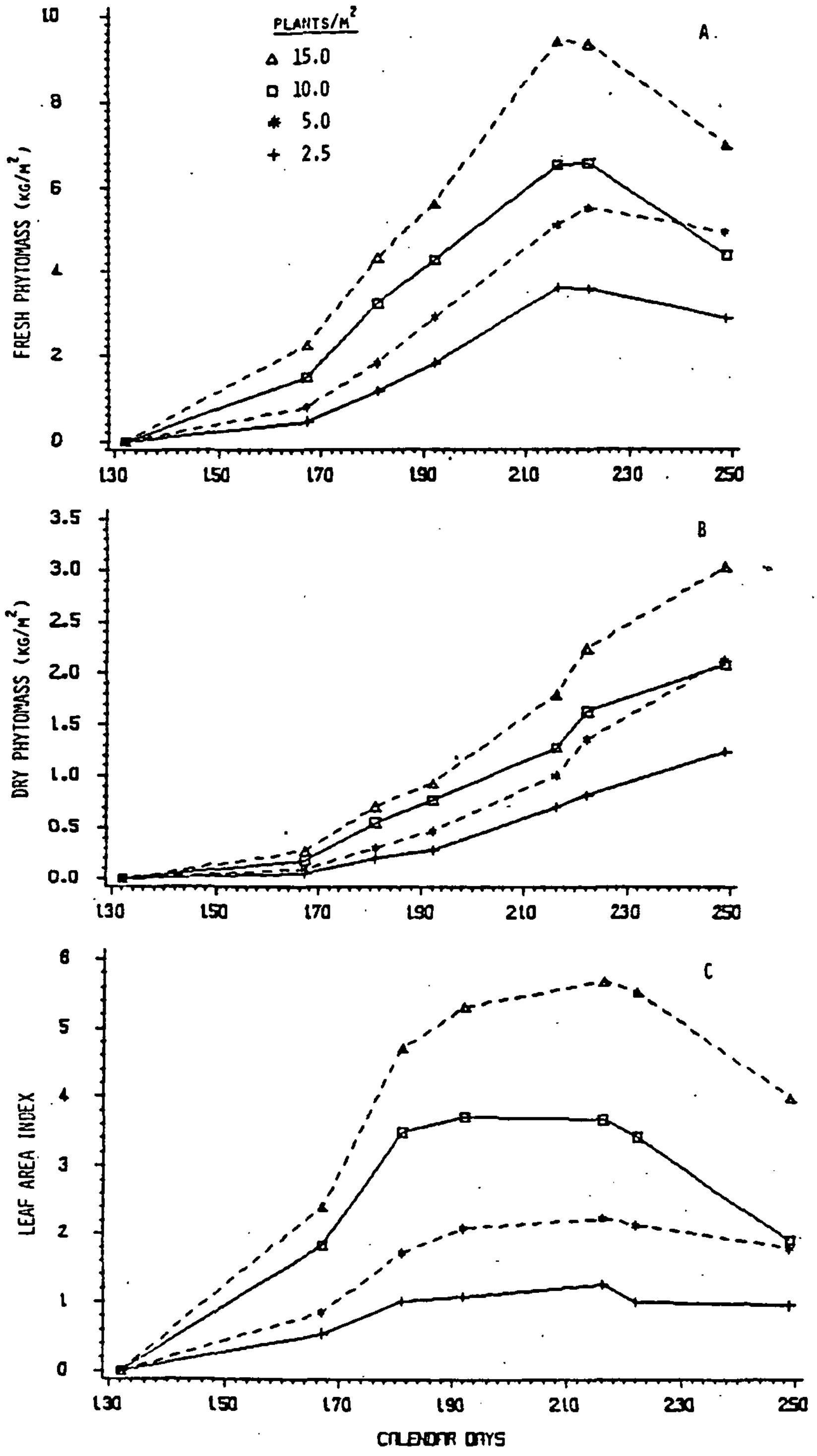

Figure 1. Changes in phytomass and leaf area index of four plant densities of corn during 1984.

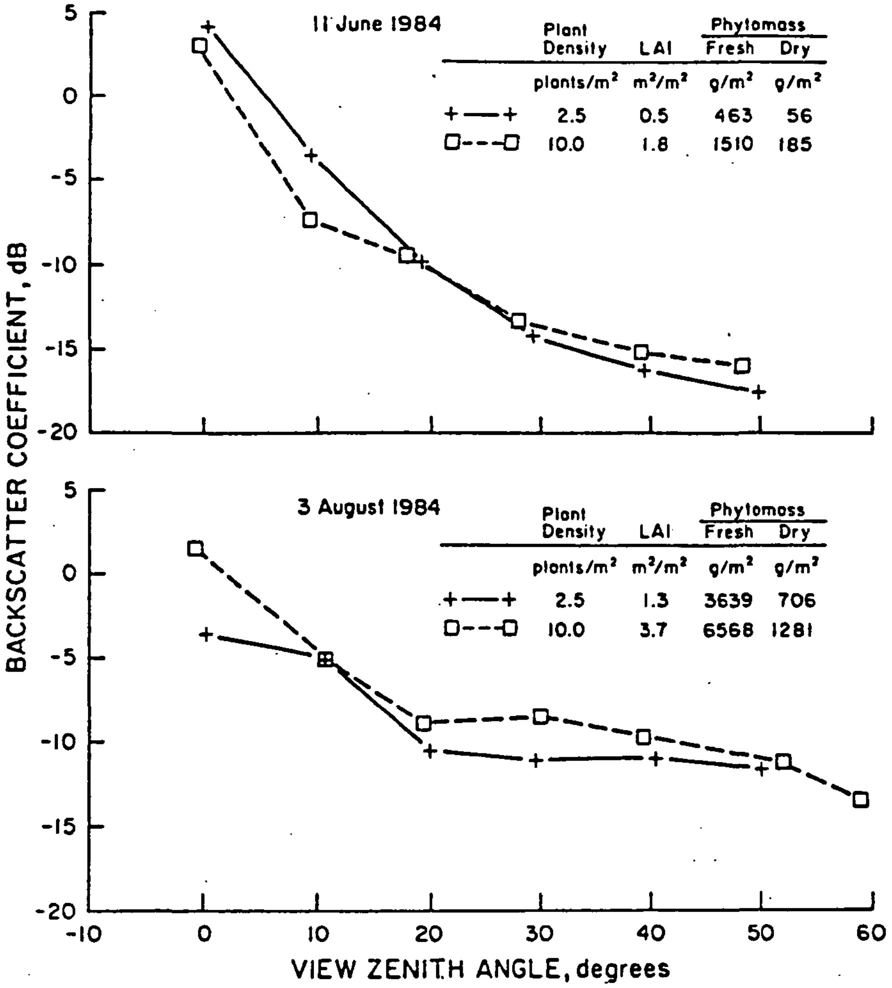

Figure 2. Changes in backscattering coefficients of two corn canopies on two dates in 1984 as a function of view zenith angle with HH polarization. Data are means of 25 observations per plot and were acquired at a view azimuth parallel to the row direction.

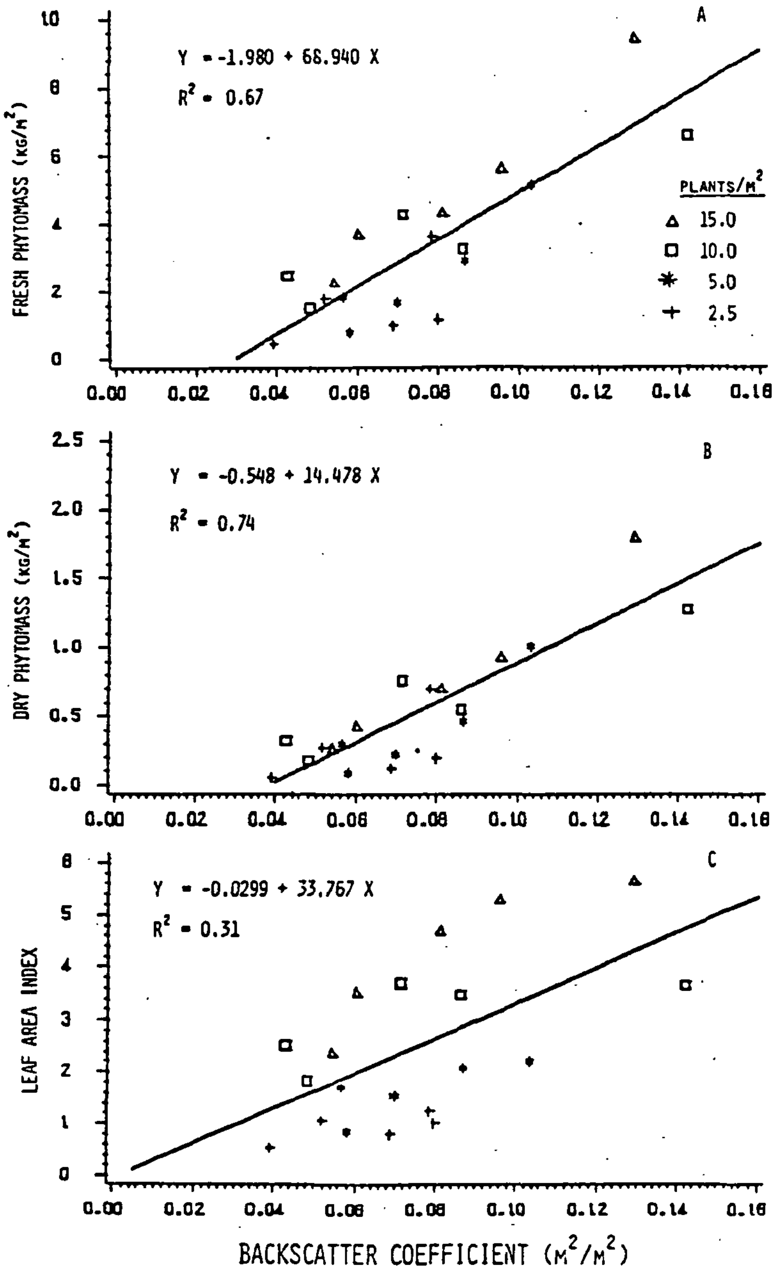

Figure 3. Relationships of phytomass and leaf area index to microwave backscatter coefficients of corn in 1984. Microwave data were acquired at a view zenith angle of 30° with HH polarization. Similar results were also observed for VV polarization.

background condition and thus enrich the information content about vegetation. Knowledge gained from these analyses will be valuable in interpreting multitemporal microwave data.

Balsam Fir Experiment

The purpose of the balsam fir C-band experiment was to examine the radar backscattering from coniferous forest canopies arranged with different densities. Balsam fir has linear flattened needles and a well defined pyramidal shaped crown. Similar trees were used for an optical reflectance experiment in 1984 (Ranson et al., 1986). In 1985, live seven year old balsam fir (Abies balsamea (L.) Mill.) trees were transplanted from a nursery to 28 liter pots filled with soil. The trees averaged 1.3 m in height with a mean crown diameter of 0.76 m. The trees were placed on a 5 m diameter rotatable platform (turntable) in an equidistant arrangement. The densities used were 0.7, 1.4, 2.0 and 3.1 trees/m^2 resulting in canopies with fresh phytomass of 1.6, 3.3, 4.7 and 7.3 kg/m^2, respectively. Other canopy measurements included needle area index, (ratio of one sided leaf area to horizontally projected ground area), dry phytomass, water content, and percent ground cover. One representative tree was sent to the University of Michigan's Radiation Laboratory for determination of dielectric properties. In addition, needle and branch angle probability density functions were measured in 1984 using balsam fir trees of similar age and growth habit.

The C-band scatterometer was mounted on the boom of the Hi-Ranger truck and positioned to view the canopies at view zenith angles ranging from 0^o (nadir) to 50^o (Figure 4). A series of backscatter measurements were made at 10^o rotation intervals of the turntable ($0-350^o$) for four polarizations (HH, HV, VH and VV). At each turntable position the average of 8 backscatter observations (in real units) was calculated. The 36 mean observations for a complete turntable rotation were averaged to obtain the the mean radar backscattering coefficient for a canopy density at each view zenith angle and polarization.

To eliminate radar backscatter from the metal turntable and pots, 0.10 m of microwave absorbing material (ie., Echosorb) was placed beneath the trees directly over the pots. The effectiveness of the absorber material was tested by measuring the backscatter of (1) the bare metal turntable surface; (2) the turntable with soil filled pots covered with absorber (no trees); and (3) the turntable arranged with trees in pots covered by absorber. The results of this test for the VV polarization are shown in Figure 5. There was a 28 db reduction in backscatter coefficient with the absorber material at 0^o view zenith angle. The trees with absorber showed a 23 db decrease in backscatter from the bare turntable and a 5 db increase over that from the absorber + pots. Similar reductions were noted from the HH, HV

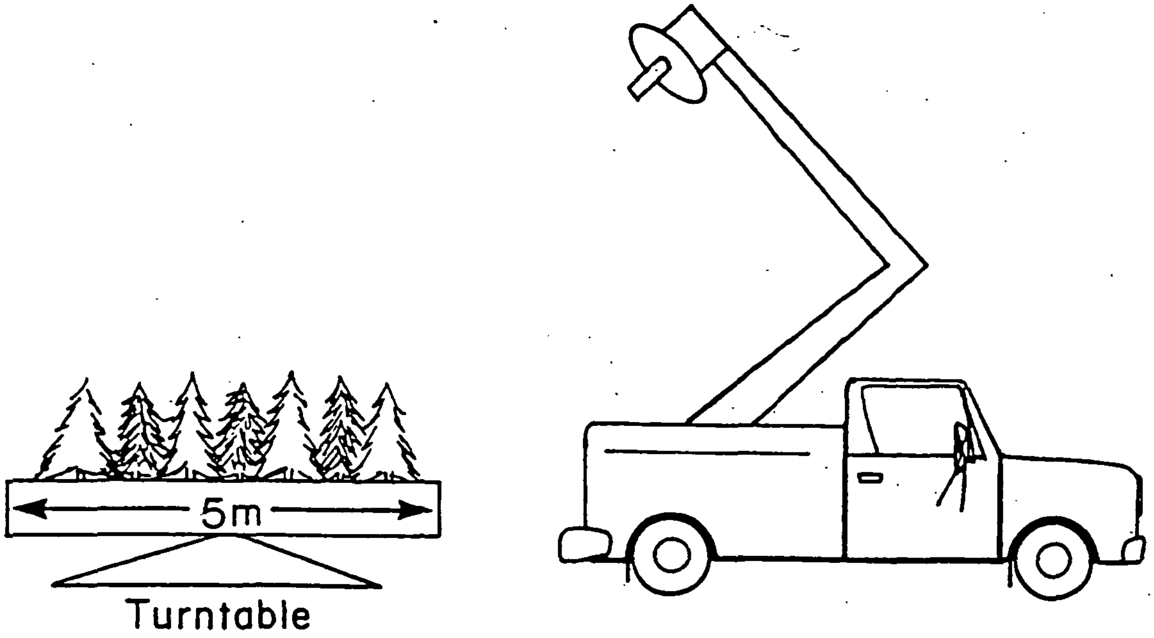

Figure 4. The C-band scatterometer was mounted on an aerial boom truck and positioned to view the balsam fir canopies on a turntable.

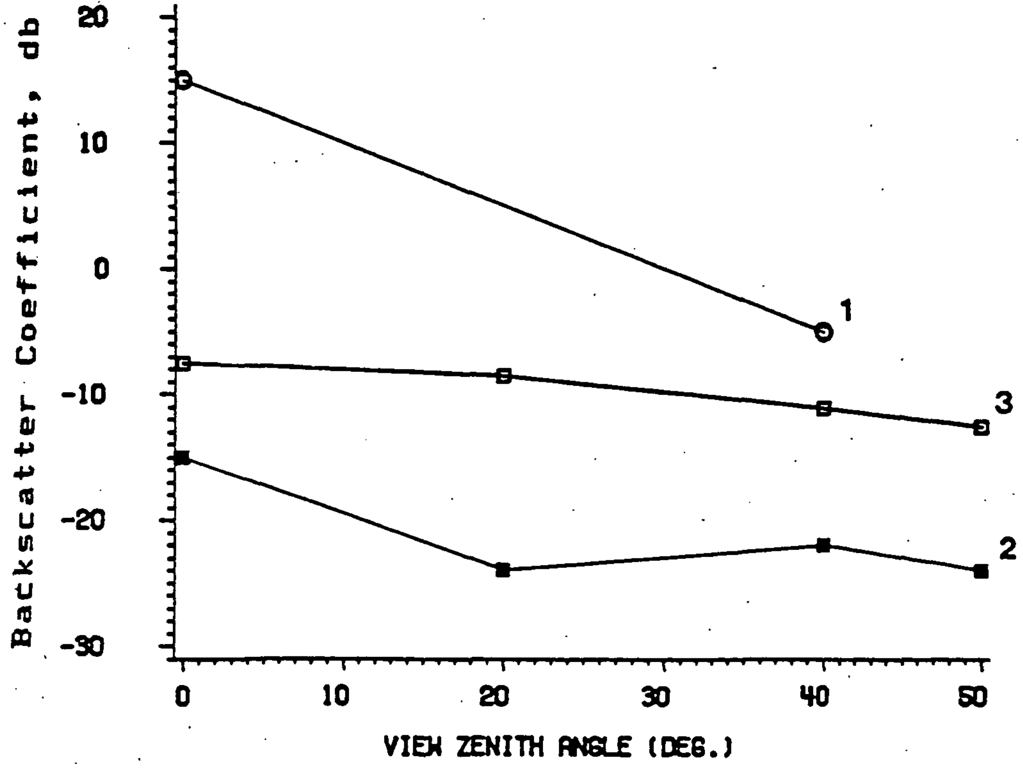

Figure 5. C-band backscatter coefficient versus view zenith angle for 1) bare metal turntable surface, 2) turntable surface with soil filled pots (no trees) covered with 10 cm of microwave absorber (Echosorb) and 3) balsam fir trees with Echosorb covering pots and bare turntable surface.

and VH polarizations as well. We concluded that the absorber material effectively minimized the radar back scattering from the background and the radar return from the scene was dominated by the canopy scattering and attenuation.

The relationships between backscattering coefficient and illumination (view zenith) angle for the balsam fir canopies is illustrated in Figure 6. There was a general decrease in radar return as view angle increased for HH and VV polarizations for all canopy densities. The HV cross polarization backscatter for the lowest density canopy decreased until 20° view zenith angle and then increased rapidly as view zenith angle increased. As the view angle increased (more vegetation in the field of view) the backscatter coefficient increased and then leveled off. It appears for this case that the scattering characteristics of the vegetation are less important for near-nadir viewing angles. The order of the curves suggests that radar backscatter coefficients increase with increasing amounts of vegetation. However, there were small differences in backscatter coefficient between the three densest canopies with 3.3, 4.7 and 7.3 kg/m^2 of fresh phytomass, respectively.

Figure 7 shows the relationship between backscatter coefficient and phytomass more clearly for view zenith angles of 0, 20 and 50° and HH polarization. The cause of the lack of difference in backscatter coefficient as the amount of vegetation increased may be attributed to attenuation of the radar signal by the outside foliated branches. Balsam fir has linear flattened needles which have length and width much smaller than the wavelength of C-band radar. Needle lengths average about 1.5 cm and needle widths average about 0.15 cm in comparison with the average radar wavelength of 6.0 cm. In a recent report Sieber (1985) observed that the outside green branches of spruce trees were the prime scattering centers for L- and X- Band radar with higher attenuation for the X-band frequency. A similar effect may be a contributing factor for our C-band measurements of balsam fir.

Accomplishments

One of the key milestones achieved in 1984 was learning how to obtain reliable data with the C-Band microwave scatterometer system. In 1984 and 1985 procedures for operating the scatterometer were refined and tested for field plots where the instrument was moved to acquire multiple samples per plot and for simulated canopies on the turntable where the instrument remained stationary and the scene moved. More than 4500 independent observations were acquired with the C-band scatterometer in the corn, soybeans, sorghum, prairie grasses and simulated forest canopies. At least three research papers are being prepared for publication. The results may be summarized by the following:

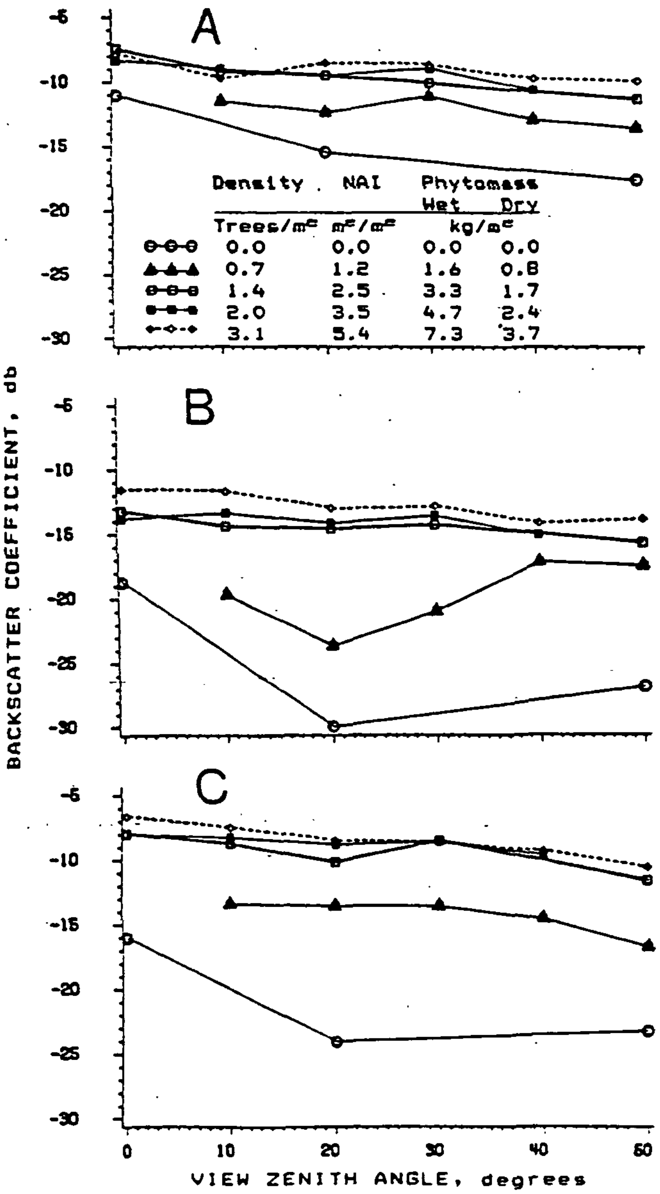

Figure 6. Relationships of C-band backscatter coefficient and view zenith angle for five densities of balsam fir and three polarizations. A) HH, B) HV and C) VV polarization.

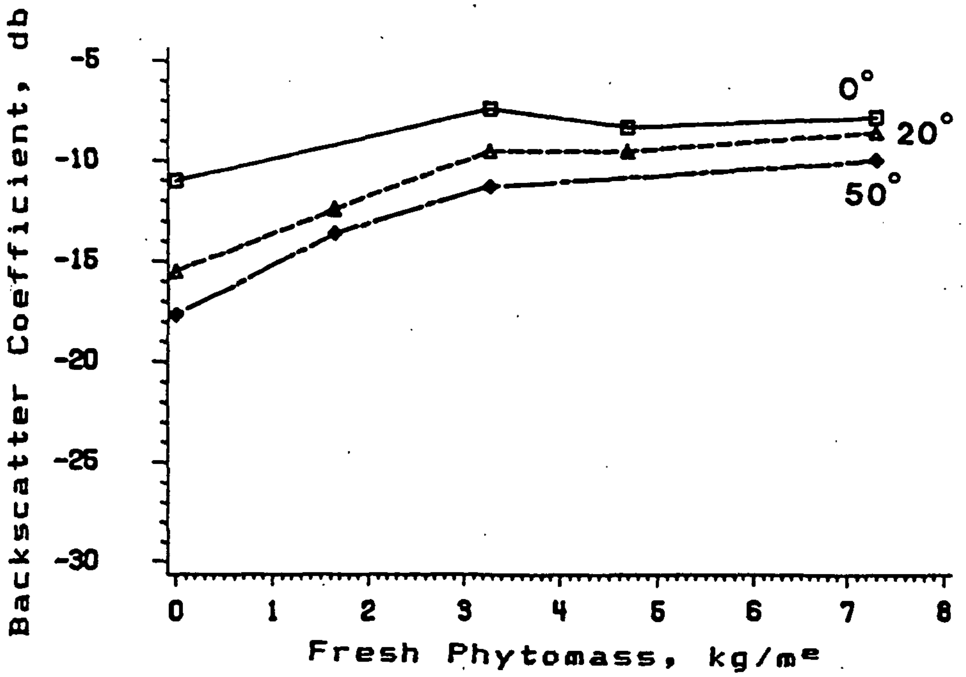

Figure 7. Relationships of C-band backscatter coefficient and fresh balsam fir phytomass at three view zenith angles.

1. As phytomass and leaf area index increased, the backscatter coefficient also increased. However, variations in soil moisture from date to date significantly affected the backscatter from all canopies. In some cases the relative ranking of the backscatter coefficients with respect to the phytomass of the canopies changed, depending on soil moisture. Analysis techniques to extract information about vegetation in the presence of "noise" due to the background are needed.

2. Tree canopies for microwave experiments can be simulated by using 10 cm of microwave absorber to obscure the background of the turntable. Many of the procedures developed for simulating canopies for our optical experiments are applicable for microwave experiments. The backscattering coefficient from the tree canopy appears to approach a maximum as fresh phytomass exceeds 3.3 kg/m^2. In these experiments the contribution from the background surface to the measured backscatter response was negligible. Additional experiments with the balsam fir trees and natural background materials (eg. soil or grass sod) should be conducted to quantify the contribution from the background.

3. Large changes in the phytomass of the grasses and legumes produced only small changes in the backscatter coefficients -- presumably because the foliage elements are much smaller than the wavelength of the C-Band microwaves (5 to 7 cm) and the background surface contributes significant radar backscatter.

4. The development of grain heads in sorghum significantly increased the backscatter coefficient (Fig. 8). These multitemporal microwave data may be valuable for determining critical stages in the development of sorghum, wheat, barley, sunflowers, and other crops.

5. An initial version of a "cloud" backscattering model (Attema and Ulaby, 1978) was implemented and exercised. A new and improved scattering model for vegetation (Eom and Fung, 1984) will be implemented in 1986 when it is available.

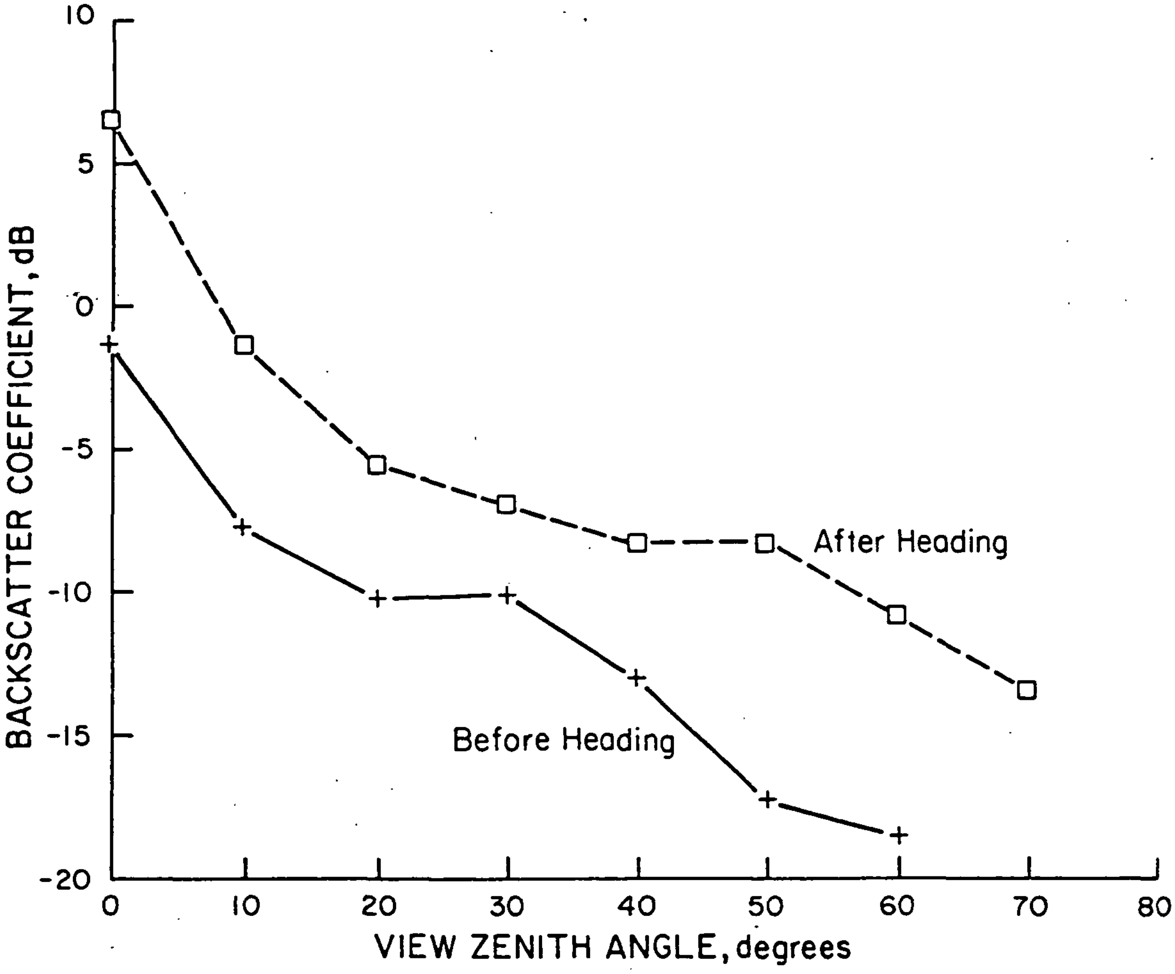

Figure 8. Changes in backscattering coefficients of a sorghum canopy before and after emergence of the panicles (grain heads). Data are means of 25 observations per plot and were acquired at a view azimuth parallel to the row direction.

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