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CROP IDENTIFICATION WITH MULTIFREQUENCY, MULTIPOLARIZATION, AND MULTIANGLE RADARS

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ABSTRACT

In a corn and soybeans test site in Webster County, Iowa, airborne radar scatterometers were used on August 19 and September 10, 1980, to investigate the backscattering properties of these crops at wavelengths of 2.3, 6.3, and 19 cm (Ku-, C-, and L-band, respectively). Both horizontal transmit-horizontal receive (HH) polarization and horizontal transmit-vertical receive (HV) polarization combinations were used at L- and C-band. Only the VV polarization combination was available at Ku-band. Measurements were obtained at 10 angles of observation from 5 to 50° in steps of 5° (referenced to the nadir). Based on these data, the following conclusions were reached: (1) Excellent separation between corn and soybeans was achieved when either C-band HV at 50° or when a defined depolarization factor was used at C-band. (2) Good separation existed at L-band also using either L-band HH at 50° or an L-band polarization factor. (3) Significant row direction effects were observed for all HH data near 10°. (4) Significant effects of surface soil moisture were observed for all configurations at L-band and C-band.

I. INTRODUCTION

The author has been investigating the active microwave or radar backscattering properties of corn and soybeans, as a part of the Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing (AgRISTARS) Supporting Research (SR) Project. The purpose of this investigation has been to understand the effects of the choice of radar system parameters (wavelength, polarization, and angle of viewing) on the information content of such radar data so far as crop identification and crop canopy condition assessment are concerned. This research has been supported by the Earth Resources Research Division at the Lyndon B. Johnson Space Center, NASA, Houston, Texas. The author is a member of the civil service staff.

The investigation was conducted over a test site in Webster County, Iowa. The site is an area of typical cropland that is about 9-by-11 km in size. The site was used for other NASA investigations into the visible, near infrared, mid infrared, and thermal infrared properties of the same crops. Also, the site was imaged by the LANDSAT Multispectral Scanner System (MSS) about every 18 days when weather permitted. An array of aircraft and helicopter based remote sensors were used in addition to the MSS to acquire the necessary data sets. During the season, ground observers made certain qualitative and quantitative measurements in specified fields in each site in order to provide a basis for understanding the information content of the remotely sensed data.

The site was covered mostly by corn (40%) and soybeans (40%) with the remaining cover being alfalfa, oats, woods, urban (a small town), farmsteads, pasture, and roads. The NASA airborne radar scatterometers were used from low flying aircraft (a C-130 aircraft at 460 m above the land surface) on two flight dates (August 19 and September 10, 1980). The radar scatterometers operated in the Ku-, C-, and L-bands at wavelengths of 2.3, 6.3, and 19 cm, respectively. At L- and C-bands, horizontal transmit-horizontal receive (HH) combinations and horizontal transmit-vertical receive (HV) polarization combinations were used. At Ku-band, only the vertical transmit-vertical receive (VV) polarization combination was available. Thus, there were five combinations of wavelength and polarization available for this investigation. For each of these combinations, radar backscattering coefficient data were measured during any given flight line run for 10 angles of viewing (referenced to the nadir) from 5 to 50° in steps of 5°. All data were acquired in a fan-shaped area from almost beneath the aircraft to a point about 500 m behind the aircraft. Thus, the data could not be used to form images of the test site; rather, the data was registered to a ground-based coordinate system and to each other to allow for the examination of the data by field and position within the field.

Flight lines were oriented in the east-west direction parallel to the major roads in the site and about 320 m north and south of those roads. Thus, the aircraft ground track and scatterometer tracks fell approximately in the middle of the 40 acre fields that were next to the roads. Ten flight lines were used with one data run per line. During the two flights, the drift (or yaw) angle was small so the measurements made at various angles did indeed fall near the same small areas on the ground after correction was made for the time lags involved between data at one angle and another angle. The actual ground track of the aircraft was determined through the use of photography taken with 30% forward overlap during each data run.

During the growing season, periodic ground observations were made of selected fields (40 corn fields and 40 soybean fields) by USDA (U.S. Department of Agriculture) personnel. These data included crop type, planting date, emergence date, harvest date, acreage, yield, production, seeding rate, previous field use, row direction, row width, pesticide application, canopy height, canopy ground cover, growth stage, surface soil moisture, weediness, fertilizer application, percent moisture of the harvested crop, and canopy appearance (color and damage). Many of these data were categorical (e.g., canopy ground cover, surface soil moisture condition, weediness, damage). Also, several important canopy and soil characteristics were not measured (e.g., volumetric surface soil moisture content, plant areal water content, canopy morphology, row height, surface roughness, row structure) as might be related to the radar properties of the crops. Nevertheless, the experiment did provide sufficient data for an initial look at the nature of the radar backscattering of corn and soybeans for the radar configurations used.

This was the first experiment ever conducted by the NASA specifically for the purpose of investigating the radar properties of crops where such a multichannel radar scatterometer system was used over an extended area. Previous airborne experiments for crop identification have been conducted using synthetic aperture radar (SAR) systems that operated at L-band[1] or at X-band or K-band[2]. (X-band wavelengths are near 3 cm; K-band wavelengths are near 1 cm.) Also, L-band spacecraft-based SAR's have acquired data over cropland [SEASAT L-band SAR HH at 20° and the Shuttle Imaging Radar (SIR-A) SAR L-band HH at 47°]. Aircraft-based SAR's are difficult to use in a quantitative investigation since calibration is difficult. Spacecraft-based SAR's are easier to calibrate; but, the two that have been used to date were not optimum for cropland surveys. These limitations will be relaxed as time goes by in future spacecraft-based SAR's such as the SIR-B in June of 1984 and the SAMEX (Shuttle Active Microwave Experiment) in 1986 and beyond. In the meantime, research is needed into the effects of sensor configuration (wavelength, polarization combination, angle of incidence) on the information content of such sensors. Again, that was the objective of the research reported in this paper.

II. RADAR SCATTEROMETERS

The radar scatterometers flown in the NASA aircraft are continuous wave, Doppler scatterometers that transmit microwave power in a fan-shaped beam toward the aft of the aircraft. After being scattered by the ground, the returned power is intercepted by the same antenna. Appropriate filtering of the returned signal results in separate power measurements for each angle range desired. The spatial resolution of the C-band radar scatterometer is about the same as that of the LANDSAT Thematic Mapper (TM), i.e., 30-by-30 m. It should be noted that radar scatterometer data are nonimaging in nature and are taken along a 20-100 m wide path below the aircraft. The various angular measurements of backscattering are moved in time so that a given record of radar scatterometer data represents the scattering properties of the ground over which the aircraft was positioned at the time given for the record.

With the 10 angles of viewing that were made for each of these five combinations of bands and polarizations (L-band HH, L-band HV, C-band HH, C-band HV, and Ku-band VV), the total number of possible remotely sensed features was 50. It was not likely that all of these would represent significant contributions to the discrimination of crop types or to the specification of canopy and soil characteristics.

III. DATA PROCESSING

The radar scatterometer data came to the author in the form of digital magnetic tape data in a specified format. The data from each flight were contained in four data files. Each file consisted of many records where each record corresponded to a set of measurements tagged by a specific time. The data were read by a program called STRIP which converted the data from ASCII to EBCDIC character codes, edited the data to remove unwanted headings, tailings, and characters, and created a file of data on the disk. After being processed by STRIP, the files were edited to form one file containing all flight lines of data. Then, the aircraft photography was examined to determine the approximate start and stop times for a segment of data for specified fields. These times and the previously created disk file were used in a data extraction step. A program called SLICE was used to implement the extractions. The output of the SLICE program consisted of many disk files, one for each field. Another program called ADD was used to add data to the files created by SLICE. Site, date, and label codes were added to the field numbers and radar scatterometer data. It was found that the use of the C-band HH data taken at 10° was most useful in checking the correctness of time intervals due to the large row direction effect that existed for that data. Row direction changes at field boundaries were common. Once the time intervals had been verified, it was a simple process to add other bands and polarization combinations to the data files by using the MERGE command available in SAS.

IV. DATA ANALYSIS

Plot programs were written to produce numerous two-channel plots of the data. After each date had been examined in this manner, the two dates (August 19 and September 10, 1980) were examined together for the subset of fields that were overflown on both dates.

On August 19, both the corn and soybean fields were in the seed development and ripening stages of growth. Heavy rains preceeded that flight date; on August 16, a widespread rain of about 5 cm (2 inches) fell over the entire test site. Rain of lesser amounts fell on August 17-19. As a result, the soil moisture at the surface was probably near field capacity (all ground enumerators reported soil moisture to be Category 3--"Soil contains considerable moisture, readily deformed by moderate pressure and can be pushed into a lump, will form a wire when rolled between thumb and forefingers, tends to stretch rather than pull free from other particles."[3] On September 10, both the corn and soybean fields were in the fully mature stages of growth, but not harvested. No rain had fallen for more than one week. Soil moisture was reported as Category 1--"Soil contains little moisture, can be broken with some difficulty between thumb and forefingers, breaks into powder or individual grains."[3]

V. RESULTS AND DISCUSSION

Comparisons of the results of this investigation with those of previous investigations show interesting differences. Most previous studies have been carried out using truck-based radar scatterometers. The primary difficulty with these investigations had been: (1) the use of wide band systems (aircraft and spacecraft radar systems to view many fields in a short period (minutes) of time, and (3) the requirement that truck-based systems scan in azimuth to collect sufficient numbers of samples to reduce the signal-to-noise ratio of the measurements. In general, the following conclusions had been reached in <u>previous experiments</u>:

1. For crop type discrimination, frequencies higher than about 8 GHz are best.[5,9,10]

2. At the higher frequencies, like polarization data proved more useful for crop identification than cross polarization data.[11,12] In fact, VV was preferred over HH.

3. In a study of the effect of revisit interval on the classification accuracies for crop type identification, Bush and Ulaby[5] found that the use of revisit intervals of 5 or 10 days produced better results than the use of 15 days.

4. Concerning the radar sensing of soil moisture conditions, Bradley and Ulaby[13], Le Toan et al.[14], Bernard et al.[15], and Jackson et al.[16] have concluded that the best radar configuration for estimating the the surface soil moisture condition (depth approximately 0-5 cm) is C-band HH at an incidence angle of 7-17°. These investigators have not found systematic effects of vegetation or of small scale surface roughness in the estimation of soil moisture using this radar configuration. Significant effects have been observed on the radar data taken with this configuration due to large scale periodic roughness caused by tillage when the field is plowed in rows for row crops such as corn and soybeans. This effect is called the for direction and row structure effect; radar

backscatter looking across rows is often much higher (10-20 dB) than when looking along rows. Ulaby and Bare[17] concluded that the row direction effect was insignificant for frequencies greater than 4 GHz. However, exceptions to this general rule were noted. Batlivala and Ulaby[18] measured a difference of 7 dB due to row direction effects for sorghum at 5.25 GHz. For bare fields, several investigators[13,19,20] have measured significant row direction effects on L-, C-, and Ku-band like polarization radar data taken near incidence angles of 15°.

Some of the two-channel scatterplots are shown in Figures 1-3. No Ku-band plots are shown since the sensor operated at Ku-band only on one line during the September 10 flight. The limited amount of data taken on that line at Ku-band showed no separation between landcover types or crop types. Also, the data taken over the one woods area and the one "small town" area are not shown. The data taken over the one alfalfa field are shown in the figures.

Figure 1 shows a scatter plot of C-band HH 10° data versus C-band HV 50° data for September 10, 1980. Each datum represents a measured pair from an individual sensor footprint or radar pixel. It is clear that an excellent separation exists between corn and soybeans in the C-band HV 50° data. The C-band HH 10° data shown poor separation for alfalfa, corn, and soybeans.

One sees the clear effects of row direction on the C-band HH 10° data. Within the corn and soybean classes are two clusters; the upper cluster is for those fields where the sensor was looking across the rows and the lower cluster is for the along row viewing. Thus, the effect of row direction on the C-band HH 10° data is approximately 6 dB. Also, alfalfa was confused with corn for this channel.

Now consider L-band data. Figure 2 shows a scatter plot of L-band HH 10° versus L-band HH 50° data. Some separation exists in the latter channel for corn, soybeans, and alfalfa. Significant misclassification also exists. Again, significant row direction effects exist for the L-band HH 10° data. It amounts to about 9 dB and is larger than that observed at C-band.

Figure 3 shows the best two channels for crop identification -- L-band HH 50° and C-band HV 50°. There are no row direction effects for this combination. The separation of alfalfa from the rest is improved (compare to other figures).

All of the above data were taken on September 10, 1980, when it had not rained during the preceeding week and when the surface soil was relatively dry. As stated before, significant rains did occur before the August 19 flight. The effect of the wet surface soil can be seen in Figure 4. Data from both dates are shown for the combination of C-band HH 10° data and C-band HV 50° data. In this figure, however, field means are used in place of pixel values. About 5-20 pixels lay within a given field. Also, the change in the two-dimension position of the data pairs is shown by a vector for each field. Note the patterns of change. Going from wet to dry conditions, the separation between corn and soybeans increases (alfalfa is not shown since the alfalfa field was missed by the aircraft during the August 19 flight). Also, there is a fairly consistent change along the C-band HH 10° direction independent of crop type or row direction. It is believed that the change in the surface soil moisture condition over the area from one date to the next was about the same. Thus, the change in the C-band HH 10° readings seems to respond well to the change in surface soil moisture condition in a way that is independent of vegetation type or row direction. The use of the absolute value of the C-band HH 10° readings to infer the absolute value of the soil moisture would not work well for these data.

The previous figures and discussion suggest that one channel (e.g., C-band HV at 50° or L-band HH at 50°) of radar data could be used to identify corn and soybeans at least in the site used on the date used (late season). However, this separation may be fortuitous in that factors such as plant water content and stage of growth may be driving the temporal characteristics of these fields in a manner that found them in a good state of separation on the flight date. Another year or another site might yield different results. It is well known that corn and soybean plants have quite different distributions of stem and leaf geometries and are different in height as well. These differences would lead to differences in the ability of each crop type to depolarize incident radar radiation. So, the author suggests that one could use a depolarization factor, D, defined as

$$D = \sigma^\circ_{HV} / \sigma^\circ_{HH} \qquad (1)$$

In decibels ($X_{dB} = 10 \log_{10}(X)$),

$$D_{dB} = \sigma^\circ_{HV}(\text{in dB}) - \sigma^\circ_{HH}(\text{in dB}) \qquad (2)$$

Since cross polarized returns are usually less than like polarized returns, D_{dB} is usually less than one. For poorly depolarizing objects, D_{dB} would be a large negative number; in other words, D would approach zero. If the like and cross polarization returns are equal, D_{dB} equals 0 dB and D equals unity.

Figure 5 shows a plot of the depolarization factor at L-band 50° versus the depolarization factor at C-band 50°. Excellent separation exists.

VI. SUMMARY OF RESULTS

In contrast to previous investigations the results of this investigation are as follows:

1. Separation of corn and soybean was poor for L-band HV 50°, C-band HH 50°, and Ku-band VV 50° data for both dates. Separation was excellent for corn and soybean fields for C-band HV 50° data and was good for L-band HH 50° data. Using C-band HV at 50°, C-band HH at 10° and 50°, the within field (excluding boundaries) radar pixels could be classified into five landcover classes (corn, soybeans, alfalfa, wooded, and "town") with an overall accuracy of 98% when the September 10, 1980, data were used. Much poorer results were found for the August 19 data when the soil surface was quite moist from recent rain. The C-band HH 50° channel was useful in separating "town" and alfalfa from the other three classes. The C-band HV 50° channel was useful in separating soybeans from corn and woods once "town" and alfalfa had been separated using the previous channel. Finally, the C-band HH 10° channel was used to separate corn from woods.

2. The use of a defined depolarization factor, D, also produced excellent separation between corn and soybeans when C-band 50° data were used.

3. Significant effects of row direction were observed for both L and C-band HH data taken near 10°. This observation at C-band through mature corn and soybean canopies disagrees with the previously accepted dogma that row direction effects are insignificant for nonirrigated row crops when vegetation canopies are present.

4. Significant effects of the vegetation canopy and/or small scale roughness were observed at the C-band HH 10° configuration. This observation disagrees with the previously accepted dogma that no systematic vegetation canopy or small scale roughness effects were present for this radar configuration. In other words, the interpretation of the C-band HH 10° channel data simply in terms of soil moisture condition without regard to vegetation cover and/or small scale roughness will not work. It is suggested that the change in radar backscatter for this configuration will be relatable to the change in soil moisture condition from day to day. Nevertheless, gradual trends in canopy condition and type will have to be taken into account in any soil moisture sensing scheme.

5. Differences in the soil moisture condition of the surface soil affected the C-band data for both HH and HV and at all angles especially in the case of the corn fields. This result implies that both soil moisture and vegetation canopy type and condition must be estimated jointly using a multichannel approach.

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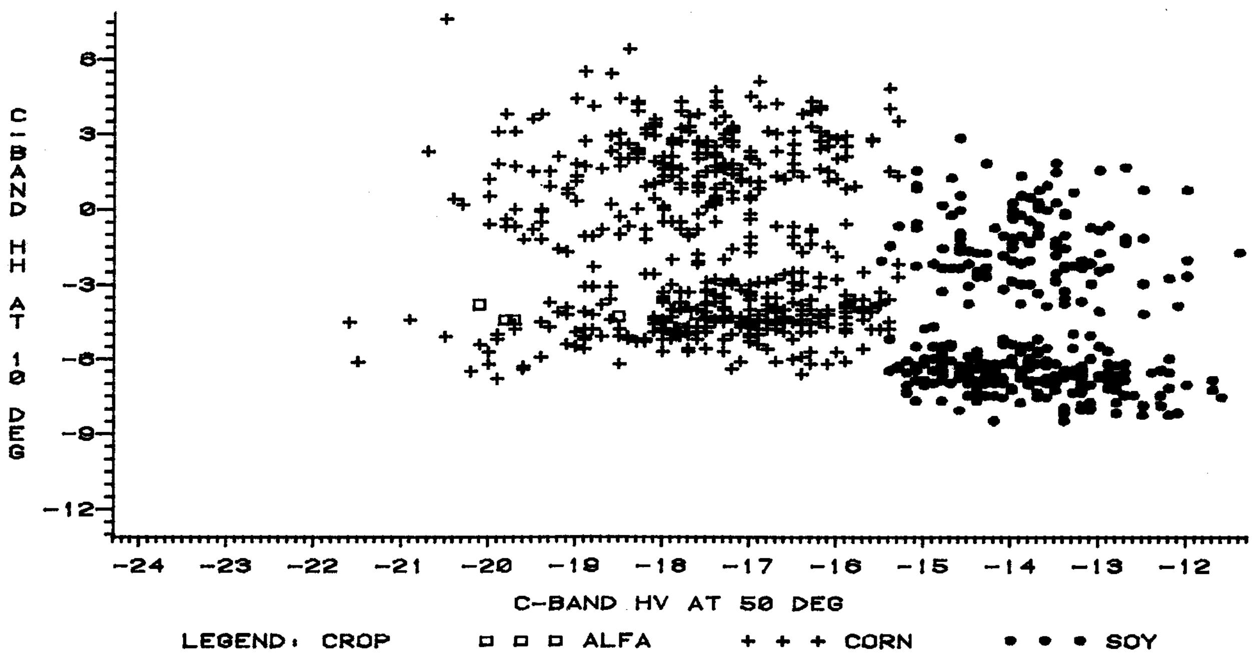

Figure 1. Scatterplot of C-band Radar Scatterometer Data, Webster Test Site, September 10, 1980

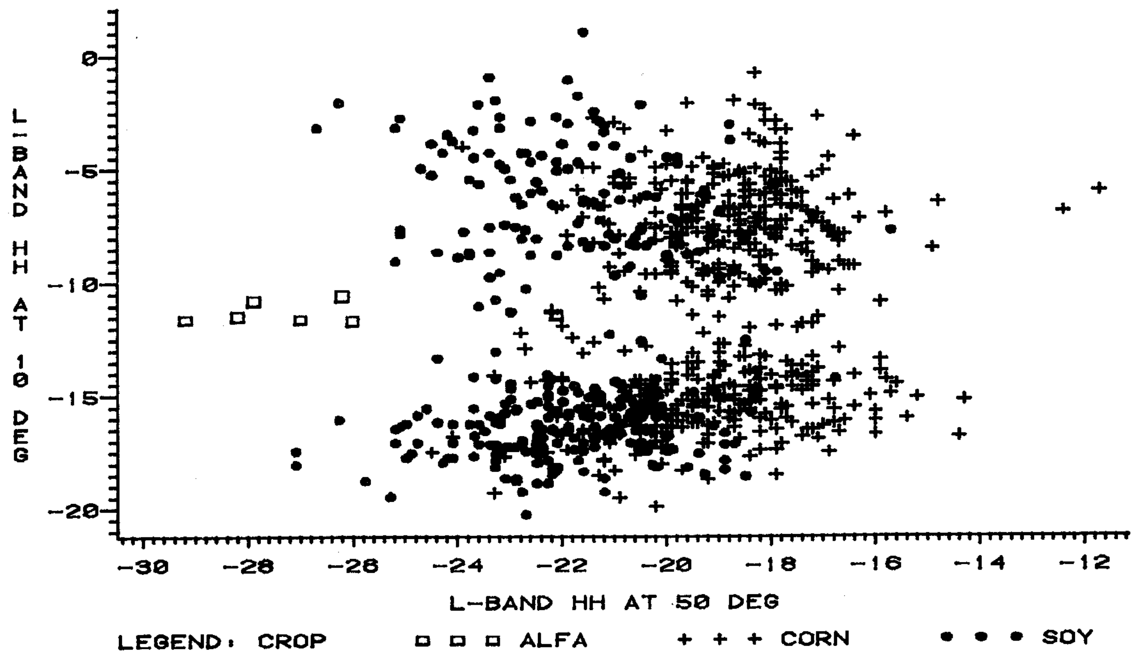

Figure 2. Scatterplot of L-band Radar Scatterometer Data, Webster Test Site, September 10, 1980

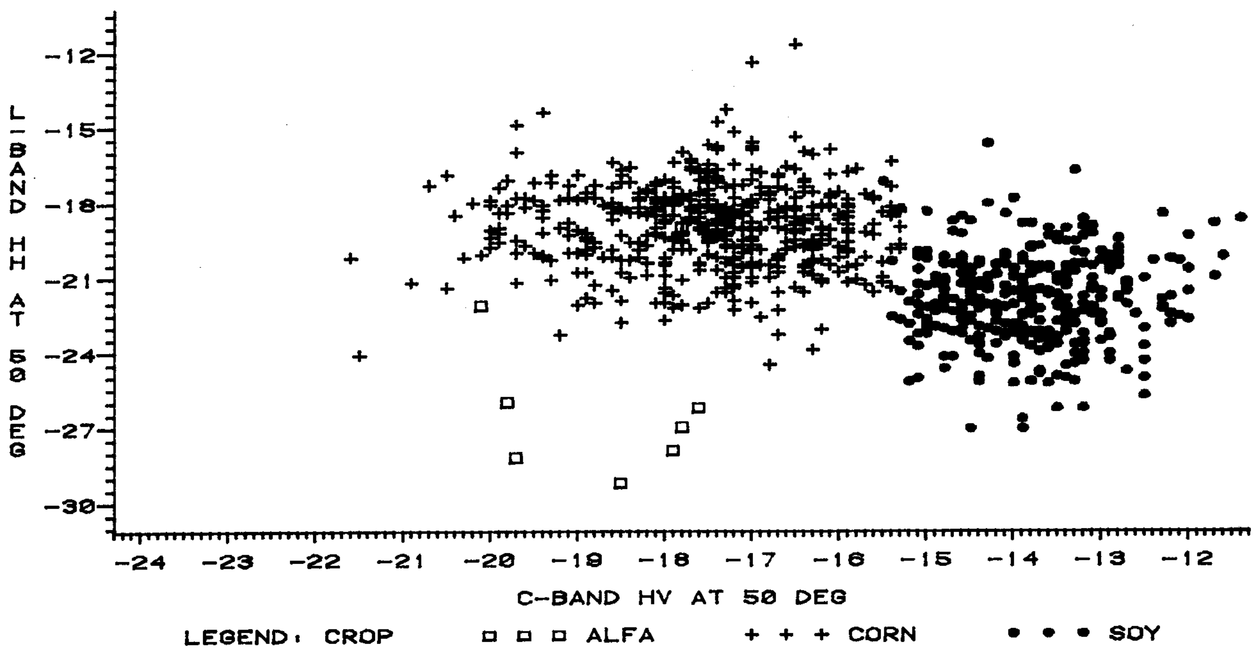

Figure 3. Scatterplot of L-band and C-band Radar Scatterometer Data, Webster Site, September 10, 1980

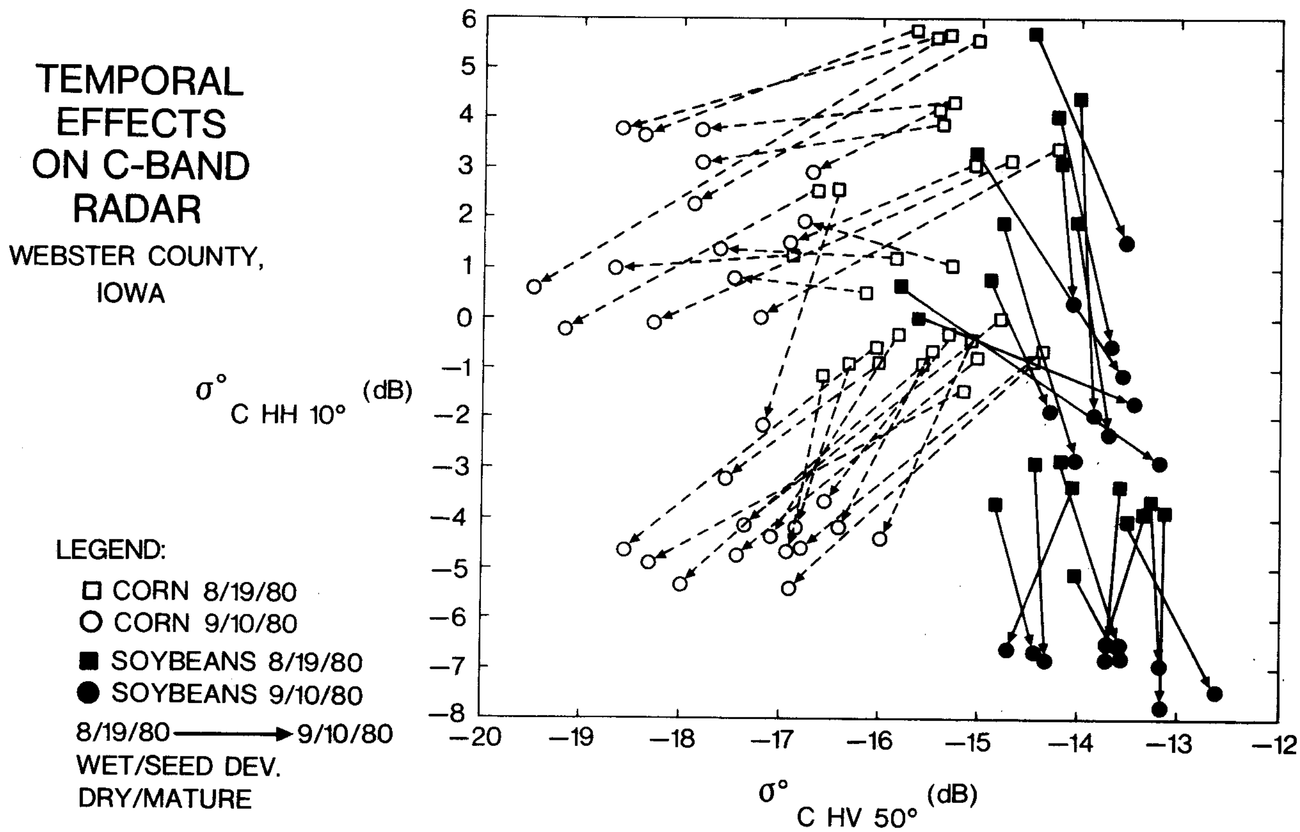

Figure 4. Temporal Effects (Soil Moisture Effects) on C-band Radar, Webster Test Site, 1980

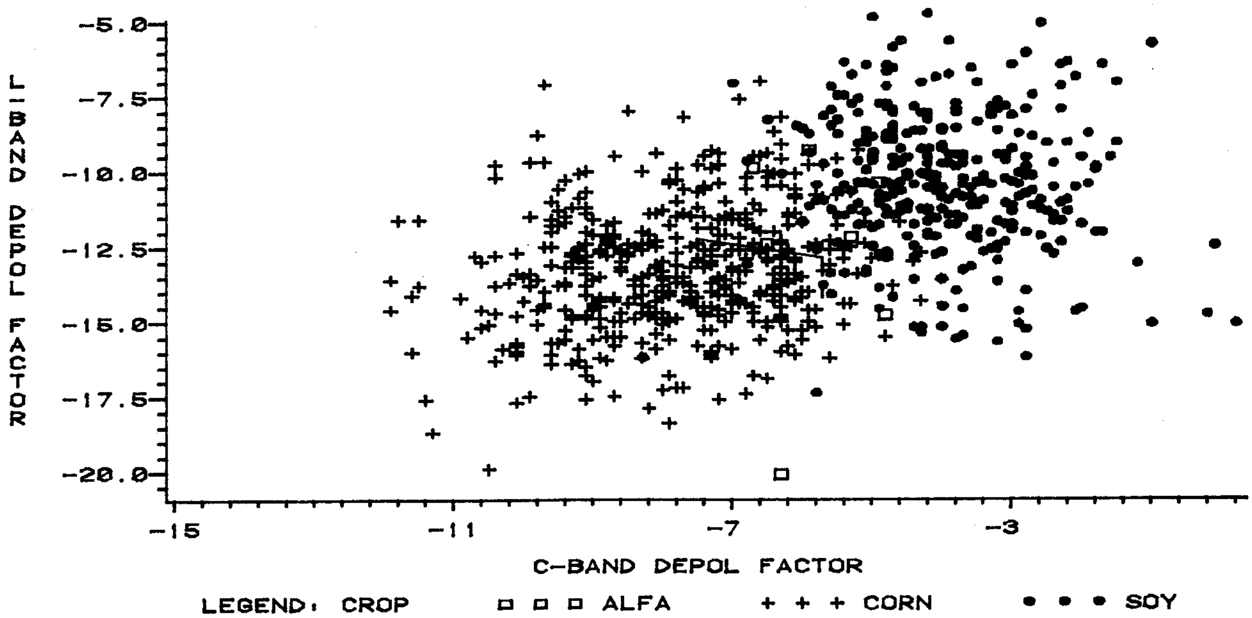

Figure 5. Scatterplot of L- and C-band Depolarization Factors, Webster Site, September 10, 1980

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