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Radar Look Direction and Row Crops

The signal strength of the radar return from row crops is affected by the look direction relative to the crop row direction.

Introduction

The value of imaging radar in agricultural land-use mapping is being constantly demonstrated[1-6]. Most studies to date have dealt with the problem of crop type identification as a prelude to other applications of interest such as the estimation of the stage of growth and the determination of the presence of stress (disease) associated with a particular crop or field.

Abstract: *Among the parameters affecting the signal strength of the radar return from row crops is the look direction relative to the crop row direction. Using a mobile truck-mounted 2-8 GHz Active Microwave Spectrometer, radar backscatter measurements were acquired from a field of sorghum with look directions parallel and orthogonal to the row direction at six incidence angles (nadir to 50° in 10° steps) for both HH and VV polarizations over the 2-8 GHz (15 cm–3.75 cm wavelength) band. The results confirm observations made from radar imagery indicating that the difference in return between the two look directions increases with wavelength and is larger for HH polarization than for VV polarization.*

The radar return signal strength is governed by two sets of parameters: (a) sensor parameters: frequency, polarization, and incidence angle; and (b) target parameters: crop geometry (height, density, row spacing, leaf structure, etc.) and plant and soil moisture contents. In the case of row crops, the direction of the propagation vector and its polarization relative to the row direction is also important[2,3]. Measurements of the backscattering coefficient σ° of a variety of crop types have been conducted to determine the radar response to variations in crop parameters[7-10]. The effect of row direction, however, has only been noted on radar imagery. To illustrate the significance of this effect, an example is shown in Figure 1 of an agricultural area in Western Kansas imaged by the Environmental Research Institute of Michigan synthetic aperture system. Two pairs of images are shown; the top pair exhibits the responses of HH (horizontal transmit-horizontal receive) and VV (vertical transmit-vertical receive) polarizations at L-band (22 cm wavelength) and the lower pair exhibits the HH and VV responses at X-band (3.2 cm). The L-band VV image was acquired on July 22, 1971 and the other three images were acquired the following day. The arrows drawn in Figure 1 point to two fields having the continuous cultivation pattern illustrated in Figure 2. One of the fields is wheat stubble 35 cm high and the other is sorghum 58 cm tall. Note that both fields, particularly the wheat stubble, exhibit on the imagery triangular quadrants corresponding to the sections imaged in a direction parallel to the row direction (weak return on L-band) as distinct from those imaged perpendicular to the row direction (strong return). Moreover, this phenomenon is more pronounced for HH polarization than VV polarization. Although on the imagery of Figure 1 the row-direction effect is not very significant at X-band, other imagery acquired during different phases of the growing cycle indicate that the pattern of triangular quadrants is observable at X-band for emergent wheat. In contrast, wheat fields with greater height were observed to display uniform tone[3]. The frequency and height dependence of the row direction effect can be explained in terms of signal attenuation through the plant biomass. When the vegetation is short, its cross-section when viewed in a direction parallel to the row direction is much smaller than its cross-section when viewed in a direction orthogonal to the row direction. At angles away from nadir, the backscatter in the former case is partly from the vegetation and partly from the ground, whereas in the latter case the backscatter contribution is almost completely from the vegetation. As the height increases, the vegetation leaves occupy a greater portion of the space between the rows, thereby making the field appear more uniform (horizontally isotropic). Since attenuation by the leaves increases with frequency, the response at X-band is mostly from the top leaves, whereas at L-band the signal can penetrate further and hence the backscatter is caused by a thicker layer of the illuminated volume. If the vegetation height (or density) is further increased, then the difference in return due to row direction at L-band will probably also disappear.

In terms of the vegetation biomass intercepting the signal, increasing the incidence angle away from nadir would roughly correspond to increasing the plant height. The converse is also true; at angles close to nadir, tall vegetation can exhibit a difference in the radar return due to row direction.

This paper is concerned with the sensitivity of σ° to row direction as a function of frequency, polarization, and incidence angle. Using a truck-mounted 2-8 GHz radar spectrometer, data were acquired from a sorghum field for look directions parallel and orthogonal to the row direction.

Experiment Description

The scattering coefficient data reported herein were acquired by the University of Kan-

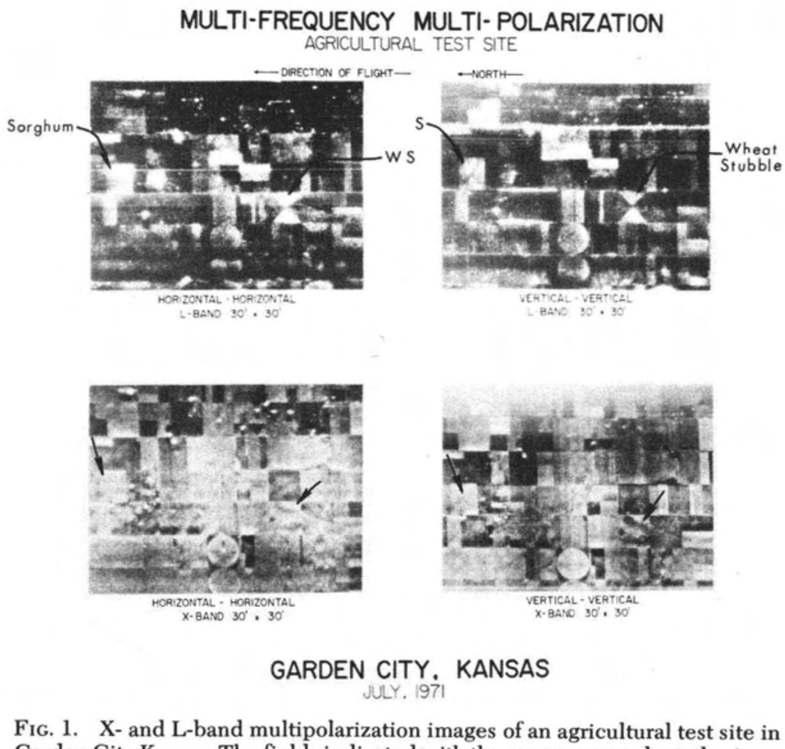

Fig. 1. X- and L-band multipolarization images of an agricultural test site in Garden City Kansas. The fields indicated with the arrows were planted using a continuous cultivation pattern.

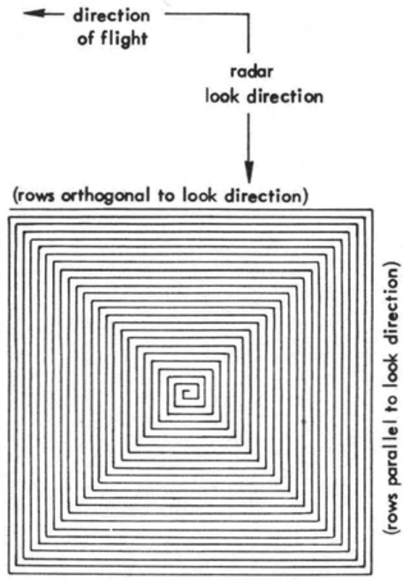

FIG. 2. Continuous cultivation pattern.

sas MAS 2-8 system[11] which is an FM-CW scatterometer capable of operating over the 2-8 GHz band. The system is mounted atop a 20m truck-mounted boom. A summary of the Microwave Active Spectrometer operational characteristics is given in Table 1.

Six weeks prior to the experiment, a field at the Texas A & M University Agricultural Experiment Station was planted with sorghum with a row spacing of 1 m. At the time of the experiment the sorghum plants had reached a height of about 2.5 m. Although initially it was planned to conduct the row sorghum part of the experiment for different plant heights, system and logistic problems delayed the start of the microwave part of the experiment. By then, the sorghum was fully grown.

A closeup view of the sorghum field is shown in the photograph of Figure 3. For reference purposes, data acquired with the look direction parallel to the row direction will be designated by "//" and those acquired with the antenna beam pointing orthogonal to the row direction will be designated by "⊥". Three sets of data were acquired on different days between July 16 and July 19, 1974. From measured soil moisture and bulk density profiles, the volumetric moisture content associated with each radar data set was calculated using the effective skin depth model of Ulaby *et al.*[12]. Each data set consisted of radar backscatter measurements at incidence angles of 0° (nadir) to 50° in 10° steps, VV and HH polarizations, and 8 frequencies between 2 and 8 GHz. To reduce the effects of signal fading and to insure proper target "representation", spatial averaging was employed by moving the truck along side the field and repeating the data taking procedure. Hence, for each frequency-incidence angle-polarization-look direction combination, data points reported in this paper represent an average of several spatially independent measurements.

DATA ANALYSIS

The radar sensitivity to the orientation of the vegetation row direction (relative to the radar look direction) is in general a function

TABLE 1. MAS 2-8 SYSTEM SPECIFICATIONS

Type:	FM-CW
Modulating Waveform:	Triangular
Center Frequencies:	2.75, 3.25, 4.75, 5.25, 5.75, 6.25, 6.75, 7.25 GHz
FM Sweep: ΔF	450 MHz
Transmitter Power	40 mW
IF Frequency: F_{IF}	50 KHz
IF Bandwidth: ΔF_{IF}	6 KHz
Antennas:	
Height above ground:	20 m
Transmitting antenna diameter:	91.5 cm
Receiving antenna diameter:	91.5 cm
Feeds:	Log periodic
Incidence angle range:	0° (nadir)–80°
Polarization:	Horizontal transmit-Horizontal receive (HH)
	Vertical transmit-Vertical receive (VV)
Calibration:	
Internal	Delay line
External	Luneberg lens

FIG. 3. A closeup view of the sorghum field under investigation.

of incidence angle, signal polarization, and frequency. The significance of each of these sensor parameters will be discussed next for only one of the three data sets partly to conserve space and mainly because the results are similar for all three cases[13].

Although angular and frequency responses will be discussed separately, they are nonetheless related. Three frequencies have been chosen to discuss the angular response; these are 2.75 GHz, 5.25 GHz, and 7.25 GHz representing respectively, the lower end, the middle, and the upper end of the 2-8 GHz band. The angular response of the scattering coefficient, σ°, measured on July 16 is presented in Figure 4 for // and $\perp$ look directions at the three frequencies. Only HH polarization data are presented here since differences due to polarization are discussed separately below (Figure 5). In general, the difference between the two curves in Figure 4 is most pronounced in the 10°-30° range at the lowest frequency. At 20°, for example, $\sigma^\circ_\perp - \sigma^\circ//$ is about 9.5 dB at 2.75 GHz compared to 4.5 dB at 7.25 GHz.

To illustrate the significance (if any) of signal polarization on the difference, $\Delta\sigma^\circ = \sigma^\circ_\perp -$

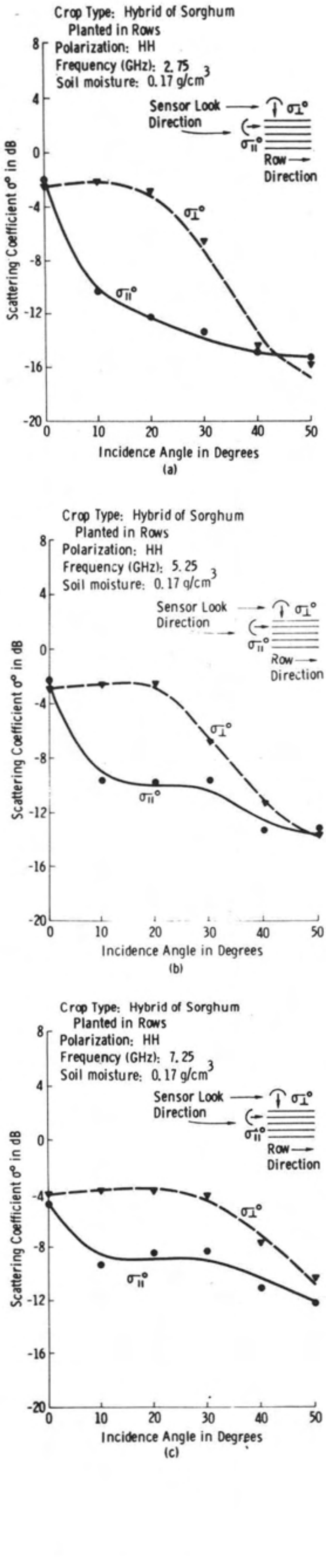

FIG. 4. Comparison of the angular response of the scattering coefficient σ° for parallel and orthogonal look directions at a) 2.75 GHz, b) 5.25 GHz, and c) 7.25 GHz.

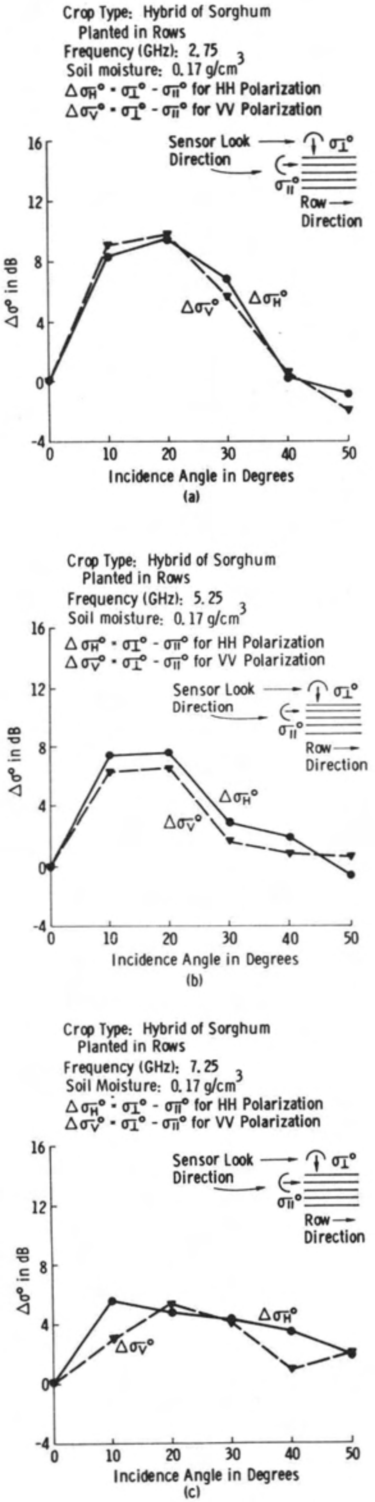

FIG. 5. Angular response of $\Delta\sigma^\circ = \sigma^\circ_\perp - \sigma^\circ_{//}$ at a) 2.75 GHz, b) 5.25 GHz, and c) 7.25 GHz.

$\sigma^\circ_{//}$, the latter quantity is plotted as a function of incidence angle in Figure 5 corresponding to the three frequencies used above. Each graph contains curves of HH and VV data. For the most part, $\Delta\sigma^\circ_H$ is larger than $\Delta\sigma^\circ_V$, which is in agreement with the L-band images shown in Figure 1.

The 2-8 GHz spectral responses of $\sigma^\circ_{//}$ and $\sigma^\circ_\perp$ are shown in Figure 6a and 6b at 20° and 50°, respectively. Consistent with earlier observations, at 20° $\sigma^\circ_\perp$ approaches $\sigma^\circ_{//}$ as the signal frequency is increased, and at 50° the look direction effect is almost completely absent across the entire band.

Concluding Remarks

The observations noted in this paper suggest the need for thorough experimental programs to document the effect of look direction (relative to the row direction) on the backscattering coefficient of row crops as a function of crop growth and the sensor parameters: incidence angle, signal fre-

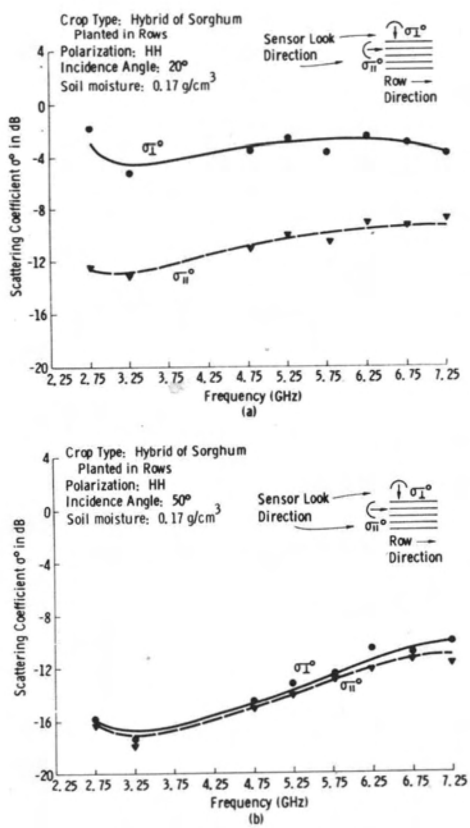

FIG. 6. Comparison of the spectral response of σ° for parallel and orthogonal look directions at a) 20° and b) 50° incidence angles.

quency, and polarization. Such information is vital for proper choice of future operational imaging radars intended for agricultural land use mapping and for proper analysis and interpretation of the imagery acquired by these systems.

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