Exploring the Information Content of Polarimetric SAR Data for Tillage and Residue Mapping

H. McNairn[1,2], C. Duguay[2], B. Brisco[3], R.J. Brown[1] and T.J. Pultz[1]

[1] Canada Centre for Remote Sensing
588 Booth St., Ottawa, Ontario, Canada K1A 0Y7
(613) 947-1815 (tel)
heather.mcnairn@ccrs.nrcan.gc.ca

[2]Université Laval
Département de géographie
Cité Universitaire, Sainte-Foy, Québec, Canada G1K 7P4

[3] Noetix Research Inc.
265 Carling Ave, Suite 403, Ottawa, Ontario, Canada K1S 2E1

***Abstract* – Although the interaction between linearly-polarized microwaves and agricultural targets has been studied extensively, far less is understood about the added information provided from polarimetric SARs. Using 1994 SIR-C data, this study examined the role of polarimetric parameters in better defining post-harvest agricultural surfaces. Preliminary results suggest that cross-pol backscatter, pedestal height and cross-pol ratios provide information on soil management practices, including type of crop residue and amount of residue cover.**

1. INTRODUCTION

For more than two decades, researchers have studied the response of microwaves to soil and crop parameters (Brown *et al*., 1993). These studies established that for non-vegetated surfaces both surface soil moisture and random and periodic surface roughness significantly affect radar backscatter. Using radar derived surface roughness estimates, tillage characteristics can be inferred, particularly when imagery is collected at shallow incidence angles (McNairn *et al*., 1996). Research has also demonstrated that using RADARSAT imagery, some information can be provided about crop residue, and that multi-date imagery can be used to monitor management practices during periods of post harvest and seedbed preparation (McNairn *et al*, 1998a). However, although an understanding is developing regarding the interaction of linearly polarized microwaves with agricultural targets, far less is understood about the added information content provided by polarimetric SARs. Some campaigns have addressed the response of polarimetric SARs to agricultural crops, but few studies have established whether polarimetric parameters can be used to describe non-vegetated surface conditions.

A quadrature or fully polarimetric SAR records all 4 mutually coherent channels (σ^o_{hh}, σ^o_{vv}, σ^o_{hv}, σ^o_{vh}) and as such, is able to represent the complete polarization characteristics of the target. An important advantage of fully polarimetric data is that the expected scattering cross-section of a scatterer for any pair of transmit and receive polarizations may be synthesized from the scattering or Stokes matrix (Raney, in press). Several preliminary studies have suggested that polarimetric SARs can be used to detect land features and to better define target parameters.

Using quadrature data collected by SIR-C, this study investigated whether polarimetric parameters can be used to better define agricultural management practices including crop residue type and amount, and tillage applications. The data set will also address the dependence of radar response from these surfaces on surface moisture conditions and the effect of incidence angle.

2. METHODOLOGY

During both the spring and fall of 1994, SIR-C data were gathered over an agricultural test site centred on Altona, Manitoba. L- and C-band quad-pol data were acquired on April 10 ($\theta = 33^o$), 11 ($\theta = 39^o$), 12 ($\theta = 44^o$) and October 2 ($\theta = 38^o$), 3 ($\theta = 43^o$) and 5 ($\theta = 51^o$). SIR-C data were pre-processed after the missions as single look complex, and were delivered to CCRS absolutely calibrated. Radiometric calibration of SIR-C data included end-to-end system characterization of the sensors and data, utilizing internal and external calibration (Stofan *et al*., 1995).

During both the April and October field campaigns, information on surface conditions was collected coincident with SAR acquisitions. Quantitative soil moisture, surface roughness and residue measurements were made on 13 fields coincident with each SIR-C overpass (Pultz *et al*., 1997). In addition, qualitative information was gathered for about 100 fields in the study site. The qualitative information recorded included residue type, a visual estimate of residue amount, direction of tillage and in the case of no-till fields, residue row direction. Major residue categories included grain, corn, canola, beans and peas.

Each of the quad-pol scenes was decompressed and then multi-looked. Bitmaps were drawn over selected fields and the following field average statistics were extracted: L- and C-band backscatter for linear and circularly polarized microwaves (HH, VV, HV, RL, RR), pedestal height and total power. In addition, co-polarization plots were generated for each field.

The Duncan Multiple Range test was used to establish residue class separability. Also, simple and multiple regression analysis established the significance of correlations between amount of residue and radar response.

3. RESULTS AND DISCUSSION

In an earlier analysis of this data set, when comparing responses from surfaces with similar residue amounts but different types of residue, L-HV or L-band pedestal height were able to separate most residue types (McNairn *et al*., 1998b). The multiple range test was run on the April 12 data set, as well as the October 5 data set, with similar results. Surface moisture conditions were wetter during the April acquisitions (by approximately 10-15%) relative to the October acquisitions. Also, due to the SIR-C look direction (orbital inclination of 57^o) relative to tillage and residue row directions, backscatter did not vary significantly as a function of row direction.

A. Simple Regression Results

For each date of acquisition, when all residue types were pooled together, correlations between residue amount and backscatter were weak (R-values < 0.45), although significant (at $p < 0.05$). These weak correlations are not unexpected, considering that significant differences in returns have been observed as a function of residue type, both in this study, and in data collected using a ground based scatterometer (McNairn *et al*., 1997). This observation suggests that in mapping the amount of crop residue cover, surfaces must first be categorized by crop residue type.

To determine within class correlation between residue amount and radar response, further analysis was based on separate crop residue type classes. To date, this analysis has focused only on grain residue fields. Correlation coefficients (R-values) for these grain residue fields were moderate and in the 0.4 to 0.6 range. In both the April and October data sets, C-HH/HV had the best results (average R = 0.603 for April and 0.544 for October), suggesting that differences between C-HH and C-HV increase with increasing residue.

Although results would suggest a moderate relationship between grain residue amount and backscatter, the slopes of the regression equations were negative for C-HH, C-VV, L-HH and L-VV. This suggests that as residue cover increases, linear like-polarized backscatter decreases. This relationship is contrary to results reported using the scatterometer (McNairn *et al*., 1997). One significant difference between these two data sets is that during the scatterometer experiment, surface roughness was constant for all test plots and surfaces under the residue were smooth. In the SIR-C experiment, not only does residue amount vary, but surface roughness also varies. In fact, there is a direct relationship between tillage of the soil surface and changes in surface roughness, and reductions in residue cover.

These simple regression results underline the difficulty in separating residue from roughness and moisture effects, although to some degree, residue amount can be inferred from surface roughness. The difficulty in resolving multiple surface reflectance contributions using a single radar configuration is also demonstrated. Regression coefficients are significantly lower than observed under a controlled experiment and thus confirms the contribution of other surface variables (included soil moisture and surface roughness) to backscatter. Nevertheless, there is still a 20-35% contribution to backscatter from differences in management application, either driven by amount of grain residue or by tillage.

B. Multiple Regression Results

A stepwise multiple regression was run using the radar parameters as multiple independent variables. Using this multi-parameter approach, correlation coefficients increased. When all residue types are pooled, R-values increased to between 0.58 and 0.64 for C-band, but did not improve significantly for L-band. For grain residue fields, the amount of variability in radar response as a function of management practices increased to about 48% (R = 0.69) for C-band and 58% (R = 0.76) for L-band.

Table 1. Comparison of R-Values of Grain Residue vs Backscatter Using Conventional and Polarimetric Parameters

Radar Parameters Included in Multivariate Analysis	April 10 N=41	April 11	April 12	Oct 2* N=30	Oct 3*	Oct 5*
C-VV(-) and C-HV(+)	.702	.647	.661	.525	NS	.639
C-ped(+) and C-RL(-)	.712	.690	.683	.529	NS	.545
L-HH(-), L-HV(+), LHH/VV (-)	.428	NS	.475	.840	.673	.736
L-ped(-) and L-max(-)	NS	.568	.492	.540	.635	.649

*limited range of residue cover NS = not statistically significant at probability level < 0.05
(-) or (+) = sign of regression coefficient

To compare the added contribution of polarimetric parameters, regressions were first run using 2 polarimetric parameters and then compared to results using conventional linear configurations (Table 1). Relative to linearly polarized variables, polarimetric parameters did not significantly improve correlations. What may be more important is the selection of parameters sensitive to both the surface roughness (negatively correlated) and residue (positively correlated) effects. In these multivariate equations, C-HV, C-pedestal and L-HV are all positively correlated with residue amount and are likely responding to multiple scattering within the residue.

C. Co- Polarization Plots

Examination of co-polarization plots for April 10 suggests that in general, surfaces with different management practices result in different scattering mechanisms, although significant within class variability exists (Table 2).

For the C-band co-polarization plots, both corn (large residue) and pea (fine residue) plots are distinct. No- or minimum till corn fields had a distinct saddle shape with C-VV returns significantly less than C-HH returns. This response is typical of double bounce reflection between vertical stalks and the terrain (Fig. 1). For very fine residue fields like peas, C-VV response was approximately equal to C-HH response and pedestal heights were generally lower than for both corn and grain residue fields. When C-HH is approximately equal to C-VV, the scattering cross-section is independent of the linear polarization orientation and is typical of surfaces considered smooth relative to the wavelength. For grains, pedestal height generally increased with higher residue levels, suggesting that a greater degree of multiple scattering is occurring on no-till fields. Also, at lower grain residue levels, C-HH approximated C-VV, but at higher levels, C-VV responses were much lower than C-HH. Most of the variability in the plots was in the 50-70% residue range where residue amounts are difficult to visually estimate and where both residue and surface roughness effects are strong.

In examining the L-band co-polarization plots, corn residue fields had the same shape as in C-band, although differences in VV and HH were more pronounced and pedestal heights were slightly higher. For peas, L-VV was higher than L-HH in almost all cases and pedestal heights were very low. This response is again typical of surface scattering. For grain fields, those with no-till surfaces had either saddle shapes or had large peaks at VV. More variability was evident for other grain residue classes, but in general, if there was a large difference in VV and HH return, residue cover was greater than 50%. In general, L-band pedestal heights were low and did not suggest a correlation with percent residue.

4. CONCLUSIONS

During the spring and fall of 1994, quad-pol SIR-C data were gathered over an agricultural test site in southern Manitoba. At the time of image acquisition, information was gathered across the site to establish soil management practices on about 100 fields.

Statistical analysis of the data determined that L-HV or L-band pedestal height separated most fields according to residue type and that if fields are first categorized by residue type, correlations between radar parameters and percent residue cover improved. Within the largest class – grain residue – about 20-30% of variability in backscatter could be attributed to differences in management application. However, results suggested that some radar parameters may be responding to surface roughness associated with tillage, while other are responding to residue cover. Since several target characteristics are contributing to backscatter from a complex surface like post-harvest fields, a multivariate approach may be required. When

Table 2. Co-Polarization Plot Characteristics for April 10

C-Band			
	Scattering Mechanisms	**HH-VV**	**Average normalized pedestal**
Corn (no or minimum till)	Double bounce	HH>VV	0.30
Peas (fine residue)	Surface	HH~VV	0.24
Grain			
< 30%	Surface	HH~VV	0.23
30 % to no-till	---	variable	0.27
no-till	Double bounce	HH>VV	0.39
L-Band			
	Scattering Mechanisms	**HH-VV**	**Average normalized pedestal**
Corn (no or minimum till)	Double bounce	HH>>VV	0.31
Peas (fine residue)	Surface	HH<VV	0.14
Grain			
no-till	Double bounce	HH>VV (EW)	0.18
	---	HH<VV (NS)	0.14
30% to no-till	---	Variable	0.14
<30%	Surface	Variable	0.14

parameters sensitive to both surface roughness and residue were included in the model, correlations improved. Preliminary examination of co-polarization plots suggest that scattering mechanisms from these surfaces can vary depending on the residue and surface roughness conditions, although variability exists in the data set. The increased pedestal associated with no- or minimum tilled fields indicates that residue does impact radar response.

5. REFERENCES

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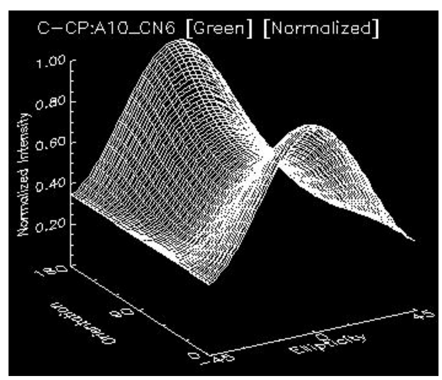

Fig. 1. C-Band Co-polarization Plot for Corn Residue

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