THE POTENTIAL OF RADARSAT-2 FOR CROP MAPPING AND ASSESSING CROP CONDITION *

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ABSTRACT

Synthetic aperture radar (SAR) research over the last two decades has confirmed that microwaves are sensitive to both soils and crop characteristics. Results using multi-temporal RADARSAT-1 imagery have confirmed that C-HH backscatter can detect differences in crop type, crop growth stage and crop indicators like crop height, biomass and leaf area index. Active microwave systems have a significant advantage over optical systems, particularly for crop monitoring, since SAR acquisitions are not impeded by cloud cover. The multi-beam modes associated with RADARSAT-1 also provide significant flexibility related to the timing, spatial resolution and incidence angle of the acquired imagery.

Building on the success of RADARSAT-1, the announcement of the launch of RADARSAT-2 opens up new opportunities for agriculture and land cover mapping. The multi-polarized configuration of RADARSAT-2 is likely to provide more information related to crop structure and crop condition. In preparation for the availability of RADARSAT-2 data, the Canada Centre of Remote Sensing (CCRS) has been gathering airborne multi-polarized imagery to assess the added information content of this multi-dimensional data. CCRS flew the airborne CV-580 SAR over two sites in Ontario during the 1998 and 1999 field seasons. These data are being used to address the sensitivity of multi-polarized SAR data to characteristics of corn, wheat and soybean crops. This paper provides preliminary results of this analysis.

1.0 INTRODUCTION

The all-weather capability of radar sensors is a significant advantage in mapping and, in particular, in monitoring the changing conditions of agricultural crops. RADARSAT-1 imagery can be acquired quickly and repeatedly over the growing season to capture the large spatial and temporal variability that is often associated with vegetation type and condition, and soil moisture. RADARSAT-1 is a single channel radar operating at C-band HH-polarization (C-HH). Although single date C-HH data can differentiate general land cover classes, multi-temporal C-HH data can provide more detailed information on vegetation type and condition. RADARSAT-1's flexible beam steering can be used to provide optimal viewing geometry for crop mapping.

Future spaceborne SAR sensors such as RADARSAT-2 will provide information not only at C-HH, but also at VV and HV/VH-polarizations. It is anticipated that a single multi-polarized image will supply much more information on vegetation type and condition than a single C-HH image. The polarization of the transmitted microwave (horizontal (H) or vertical (V)) dictates which components of the vegetation and soil contribute to the total amount of energy scattered back to the SAR sensor. Vertically-polarized microwaves (V) couple with the predominant vertical structure of most vegetation and as a result, penetration of the signal through the canopy is reduced. VV-polarized radar returns thus provide good contrast among vegetation types that have different

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vertical canopy structures. Differences in this vertical structure that result from changes in the vegetation growth stage or the health of the vegetation may also be detected in VV-polarized images. At steep incidence angles, horizontally-polarized microwaves tend to penetrate the canopy to a greater extent than vertically-polarized waves and hence HH images tend to provide more information about the underlying soil condition. However, the "coupling" of both soil and vegetation information in the total C-HH backscatter can make the extraction of information about the vegetation itself difficult. Cross-polarized radar returns (HV or VH) result from multiple reflections within the vegetation volume. C-HV and C-VH images are sensitive to crop structure within the total canopy volume and thus provide information that is complementary to HH and VV imagery.

In preparation for RADARSAT-2, the Canada Centre for Remote Sensing (CCRS) has acquired airborne polarimetric SAR data over sites in Ontario, Canada. These data are being used to study the utility of C-HH and multi-polarised C-band radar data for agricultural applications including crop type classification, biomass assessment and the monitoring of crop development and condition. This paper describes the data acquisition campaign and reports on early results from analysis of these data sets.

2.0 DESCRIPTION OF DATA ACQUISITION AND DATA ANALYSIS

During the 1998 growing season, the airborne CV-580 acquired C-band polarimetric data over a site just outside of Ottawa, Canada. Data were acquired once in June (19th) and twice in July (9th and 29th) at incidence angles of 37º to 67º. Coincident with the airborne acquisitions, supporting ground data were collected in 10 core fields including 5 corn fields, 2 wheat fields and 3 soybean fields (Table 1). Crop type (alfalfa, barley, corn, oats soybean, wheat) was recorded on a further 300 fields within the study site.

Two corner reflectors and two PARCs (Polarimetric Active Radar Calibrators) were deployed during the airborne acquisitions. Polarimetric processing and radiometric calibration of the airborne data was accomplished using the CCRS programs POLGASP and COMPLEXCAL. In addition to the airborne data, RADARSAT-1 Fine Mode (F3F (41º-44º) and F5F (45º-48º)) imagery was acquired on 23 June, 10 July, 17 July and 3 August 1998 over the Ottawa site. For each core field and each field surveyed for crop type, averaged sigma nought values were generated for all four Fine Mode RADARSAT-1 acquisitions. From the airborne data set, field averaged sigma nought values were generated in HH, HV, VV, RR (circular co-polar), RL (circular cross-polar), and LL (circular co-polar) polarizations.

To date, analysis has been completed on only the July 9th airborne data. Incidence angles on the airborne imagery varied by 30º across the swath. To minimize the influences of incidence angle effects on field to field comparisons, fields were grouped into three classes (37-46º; 47-56º; 57-67º) prior to any analysis. Field averaged backscatter values extracted from the airborne data were then used in Gaussian maximum-likelihood classifications. Successive evaluation of the results by means of confusion matrices and the Kappa coefficient allowed for a direct assessment of the classification capacity of the linear and circular polarizations. In contrast to the overall classification accuracy, the Kappa coefficient accounts for errors of omission and commission and the effects of chance agreement and is thus considered a more robust indication of classification accuracy. Since the aim was to assess relative classification accuracies of multi-polarized combinations, the same data set was used for both the design of the classifier and the evaluation of the classification results.

Crop condition data were available for only 10 core fields and consequently, sample numbers were not large enough to complete a statistical analysis. However, the sensitivity of RADARSAT-1 and multi-polarized configurations for crop condition assessment could be qualitatively assessed through visual comparisons and by plotting field averaged sigma nought values.

3.0 PRELIMINARY RESULTS

Table 2 provides classification results for the July 9th airborne acquisition. These classification results clearly demonstrate the advantage of multi-polarized data sets for crop type mapping. The HH-HV-LL 3-polarization combination had the highest Kappa coefficient (0.92). However, the most significant conclusion is drawn from the relative classification accuracies of the multi-polarized and single polarization configurations. These results suggest that the choice of polarizations within the 3-band combination is less important. All three linear and all three circular polarizations appear in one of the top three band combinations. The values in Table 2 also indicate that the greatest difference in accuracy is observed when comparing the single and dual-polarization results. In comparing results using a single polarization, the highest Kappa coefficient was associated with C-HV. The cross-polarization did particularly well at separating grain crops from other crops, relative to the other single polarizations.

The primary difference between RR and LL circular polarizations is related to the direction of rotation (clockwise versus counter-clockwise) and consequently, both polarizations have similar interactions with the target. This symmetry is apparent in Table 2 and from visual interpretation of the within field variability observed for each polarization (Figure 1). Unlike HH and VV, these two circular polarizations interact similarly with the crops. Consequently, no additional crop information is provided when both RR and LL polarizations are included.

As part of the evaluation of both linear and circular polarizations for crop mapping, field average sigma nought was plotted as a function of incidence angle, for each crop type and for all fields surveyed. Scatter plots for each linear polarization as well as the RL circular polarization are provided in Figure 2. These plots suggest that although linear polarizations, and in particular C-HH, are quite sensitive to the effect of incidence angle, the RL configuration has a reduced sensitivity. Although these results are only preliminary, this reduced sensitivity would be an advantage for crop monitoring where various beams must be combined.

The classification results suggest that multi-polarized configurations, which include either linear or circular polarizations, can detect crop type differences. However, the Ottawa data was also used to assess the applicability of SAR data for providing crop condition information. Plots of field average backscatter over the growing season did indicate that the RADARSAT-1 C-HH configuration was sensitive to changes in crop variables such as biomass and growth stage. However as demonstrated in Figure 3, C-HH backscatter from corn quickly saturates once the corn plant reaches a height of approximately 1 metre. Although C-HH backscatter appears to be sensitive to differences in crop height among the 5 core corn fields early in the season, once crop growth exceeded this height backscatter differences among the fields was significantly reduced. Further analysis is required to assess the significance of this saturation effect on other polarizations. However, a preliminary examination of the July 9th airborne data suggests that sensitivity to differences in plant height (and perhaps other crop variables) is polarization dependent. In Table 3, the RL circular polarization is much more sensitive to differences in field average crop height among three corn fields with similar incidence angles. The difference in backscatter between the two fields with similar crop heights (SC3 and SC4) is small for most polarizations. The smallest difference between SC3 (vegetative growth stage) and SC4 (reproductive growth stage) is for the RL circular polarization, indicating that although these two fields are in different developmental stages, RL is insensitive to this change in developmental stage. However for the RL configuration, an almost 3 dB difference is observed when these two fields are compared with the third field (Field 25). Field 25 was planted at a later date and consequently corn development is behind in this field relative to SC3 and SC4. The sensitivity of backscatter to differences in crop growth stage will complicate the classification of crop type. The circular polarizations also appear to provide some interesting information related to within field crop variability (Figure 1). For both wheat fields, RL, RR and LL detect differences in the field not detected on optical data (Landsat TM (August 2) and IRS-1C (July 18)) acquired over the site. Although some differences are visible at C-HH, variability is better defined in the circular polarizations. For the 5 core corn fields, in general, none of the remote sensing imagery detected within field variability.

4.0 CONCLUSIONS

Airborne polarimetric and RADARSAT-1 data acquired over a site near Ottawa, Canada, indicated that multiple linear and circular polarizations could provide crop type and crop condition information. Crop type classification requires a data set with multiple polarizations, although the choice of polarization is less important. Circular polarizations appear to provide information about crop condition not always evident on the optical or linear combinations. The results presented in this paper are preliminary and analysis is required on the two remaining airborne acquisitions. The causes of the within field variability must also be investigated and variable rate yield data are available for some fields. As well, as part of CCRS' 1999 precision agriculture campaign in southern Ontario, PROBE-1 hyperspectral and CV-580 airborne polarimetric SAR data were acquired. Processing of this data is also planned in order to investigate the synergy between the optical and SAR imagery.

5.0 ACKNOWLEDGEMENTS

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Table 1. Ground Reference Data for Core Fields (Ottawa, 1998)

Variable	Number of Observations
Crop Structure	
Row direction	1 measurement per field
Row spacing (cm)	1 measurement at 5 locations in field
Plant spacing (cm)	1 measurement at 5 locations in field
Crop Height (cm)	1 measurement at 5 locations in field
Stem diameter (cm)	4 measurement at 5 locations in field
LAI (m^2 m^{-2})	1 measurement at 5 locations in field
Yield (t ha^{-1})	Variable rate
Soil Structure	
Chain length (cm)	1 measurement at 5 locations in field
Ridge height (cm)	1 measurement at 5 locations in field
Ridge spacing (cm)	1 measurement at 5 locations in field
Plant Water Status	
Total plant fresh (gr)	1 sample of 0.25 m^2 at 4 locations in field
Total plant dry (gr)	1 sample of 0.25 m^2 at 4 locations in field
Gravimetric water content total plant (%)	4 data points per field
Soil Water status	
Volumetric water content 0-5 cm (%)	1 measurement at 5 locations in field
Volumetric water content 0-10 cm (%)	1 measurement at 5 locations in field

Table 2. Airborne CV-580 Classification Results (Incidence Angles 46°-57°) for July 9th Acquisition

				Percentage correct			
	Kappa	**Var. Kappa**	**Total**	**Alfalfa**	**Corn**	**Soybean**	**Grains**
HH, HV, LL	0.9171	0.0012	94	90	95	96	93
HH, HV, RR	0.9008	0.0014	93	90	95	96	87
HV, VV, RL	0.8514	0.0020	90	90	97	78	87
HH, RL, LL	0.8496	0.0022	90	80	92	91	87
HH, RR, RL	0.8485	0.0022	90	80	95	91	80
HV, RR, RL	0.8309	0.0026	88	100	92	74	93
HH, HV, VV	0.8177	0.0027	87	90	82	91	93
HH, VV, RR	0.8145	0.0026	87	80	95	91	67
HV, RL, LL	0.8134	0.0028	87	100	92	70	93
HH, HV, RL	0.7997	0.0029	86	80	84	87	93
HH, VV, LL	0.7980	0.0027	86	70	95	91	67
HH, VV, RL	0.7976	0.0027	86	60	95	87	80
HH, RR	0.7827	0.0028	85	80	92	96	53
HH, LL	0.7491	0.0031	83	60	92	96	53
HH, RR, LL	0.7331	0.0033	81	70	89	91	53
VV, RL, LL	0.7299	0.0033	81	30	95	83	80
VV, RR, RL	0.7120	0.0034	80	20	95	83	80
HH, HV	0.6870	0.0041	78	80	71	78	93
HV, VV, RR	0.6155	0.0047	73	70	76	65	80
HV, RL	0.6071	0.0046	72	80	74	57	87
HV, VV, LL	0.6009	0.0048	72	70	74	65	80
VV, RL	0.5973	0.0036	72	20	95	83	33
RR, RL, LL	0.5855	0.0048	71	70	76	61	73
HV, VV	0.5822	0.0050	71	70	76	57	80
HH, VV	0.5086	0.0049	66	50	79	74	33
RR, RL	0.5070	0.0049	66	10	82	61	73
RL, LL	0.5070	0.0049	66	10	82	61	73
HV, RR, LL	0.4761	0.0053	63	80	66	35	87
HV, RR	0.4760	0.0057	64	70	71	35	87
HV, LL	0.4436	0.0059	62	70	68	30	87
HH, RL	0.3923	0.0059	57	50	55	48	80
VV, RR, LL	0.3681	0.0050	53	80	50	52	47
VV, RR	0.2929	0.0058	50	30	50	52	60
VV, LL	0.2716	0.0060	49	30	50	48	60
HV	0.2508	0.0056	45	30	26	61	80
RR, LL	0.2439	0.0054	45	70	45	43	33
VV	0.2317	0.0056	47	0	47	52	67
RR	0.2305	0.0055	47	0	50	52	60
LL	0.2252	0.0056	47	0	53	48	60
RL	0.2242	0.0054	45	0	47	52	60
HH	0.2127	0.0050	44	60	50	52	7

Table 3. Sensitivity to Corn Condition as a Function of Polarization

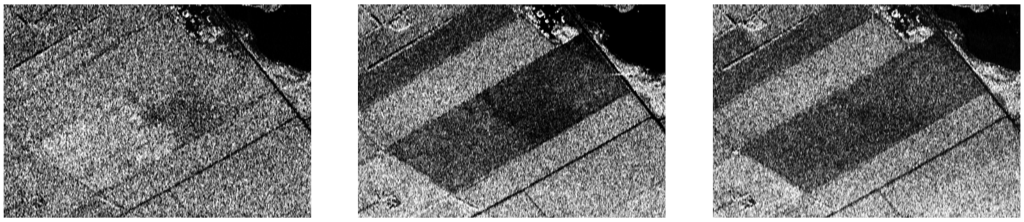
Ancillary Data

Field ID	**Growth Stage**	**Crop Height (cm)**	**LAI (m2m-2)**	**Total Plant Gravimetric Water Content (%)**	**Volumetric Water Content 0-5 cm (%)**	**Incidence Angle**
Field 25	vegetation	92.4	1.7	91.9	18.6	39.1
SC4	reproduct.	223.4	2.4	89.1	13.9	39.8
SC3	vegetation	245.0	3.0	85.9	16.0	45.6

Backscatter Difference in dB as a Function of Polarization

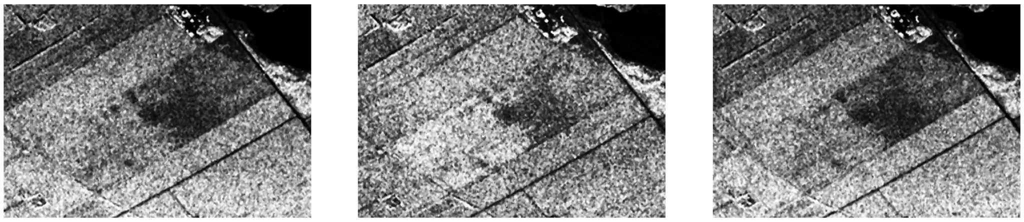
	Polarization					
Case	HH	HV	VV	RR	RL	LL
SC3 – Field 25	1.47	0.94	0.73	0.11	2.72	0.12
SC4 – Field 25	2.68	1.92	1.44	1.77	2.93	1.77
SC4 – SC3	1.21	0.98	0.71	1.68	0.21	1.65

Linear Polarizations



HH HV VV

Circular Polarizations



RR RL LL

Figure 1. Polarization Comparison of a Wheat Field Using Airborne SAR Imagery from July 9, 1998. Within-field variability is most pronounced in the circular polarized (RR, LL, and RL) images. During this acquisition, the wheat was approximately 1 metre in height and was beginning to senesce.

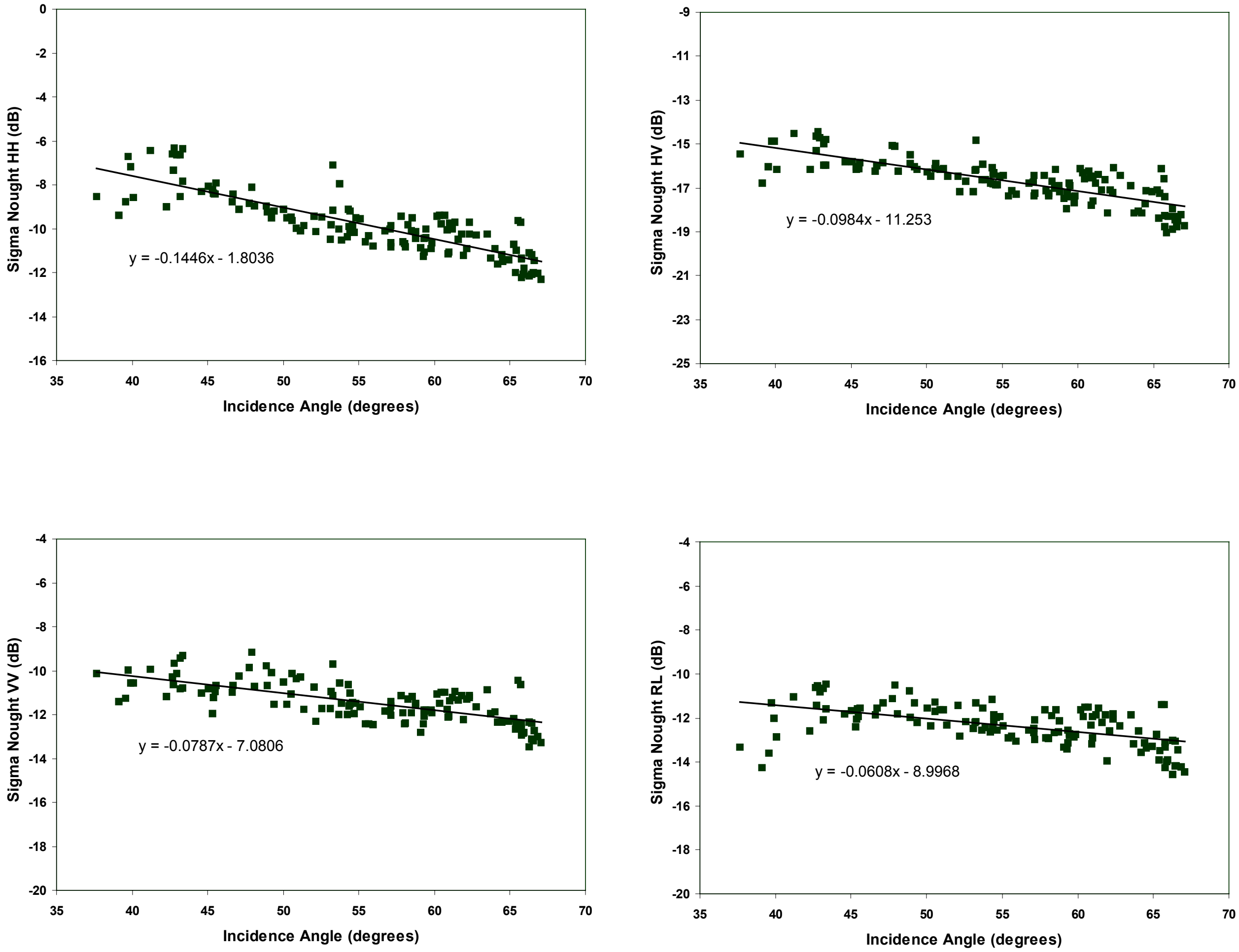


Figure 2. Backscatter as a Function of Incidence Angle. In these graphs, backscatter from all corn fields are plotted as a function of incidence angle, for each linear polarization as well as the RL circular polarization. As demonstrated in this figure, RL is least sensitive to variations in incidence angle.

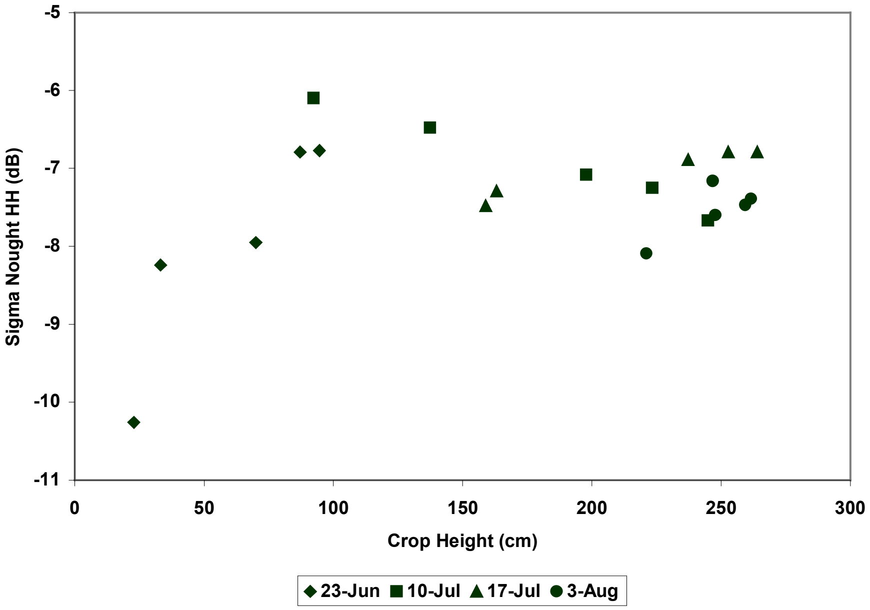


Figure 3. RADARSAT-1 Backscatter from Corn Over the Growing Season. This figure illustrates that although C-HH backscatter is sensitive to changes in corn height early in the season, once crop height exceeds about 1 metre, RADARSAT-1 was no longer sensitive to further changes in height.