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Extraction of Crop Information From RADARSAT-1 Imagery

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Abstract

During the 1997 growing season, the Canada Centre for Remote Sensing acquired 10 Standard and Fine Mode RADARSAT scenes over an agricultural test site centred on Carman, Manitoba (Canada). One purpose of this multi-year project was to address the information content of RADARSAT data for mapping crop type and for extracting information on crop condition. The application of RADARSAT for extraction of crop information is particularly attractive because of the all weather capability associated with SAR acquisitions and the sensitivity of microwaves to canopy structure and moisture.

During the data acquisition phase of the project, RADARSAT imaged a wide range of agricultural crops, at various developmental stages. In addition to the radar imagery, SPOT XS, Landsat Thematic Mapper and IRS-1C PAN optical imagery were acquired. During the period of peak biomass, crops were characterized on more than 300 fields across the site. In addition, within-field crop information related to crop condition (biomass, height and plant water content) was gathered on 12 fields across the study site.

Results have indicated that the best separabilities among crop types were observed when crops were in the process of seed development. Also, multi-date RADARSAT and optical data appeared to improve discrimination of crops, although separating spring wheat remained difficult. Preliminary analysis has indicated that both RADARSAT and satellite optical data provide information related to crop condition.

Introduction

A number of agricultural remote sensing applications, including crop monitoring, require frequent repeat coverage or require data acquisitions during critical crop development periods. In the past, the infrequent revisit schedule of earth observation satellites, and the obstruction of data collection as a result of cloud cover, has impeded the use of satellite data for agricultural mapping and monitoring. However, the all weather capability of SAR means that reliable earth observation data can be gathered to assist in establishing information on crop type and crop condition.

A large number of previous studies, using primarily ground-based scatterometers or airborne SAR systems, have demonstrated the ability of K-band (Bush and Ulaby, 1978), X-band (Hoogeboom, 1983), C-band (Brown et al., 1992) and L-band (Ulaby et al., 1980) radar to discriminate crop cover classes. Other research has reported the improvement in crop classification when both visible-infrared and active microwave data are used together (Rosenthal and Blanchard, 1984) and has demonstrated the advantages of multidate visible-infrared and SAR datasets (Brisco and Brown, 1995). Numerous other studies have related backscatter to indicators of crop condition or crop vigor including plant moisture content (Ulaby and Bush, 1976), leaf area index (Prévot et al, 1993) and crop height (Rosenthal et al., 1985).

The flexibility associated with RADARSAT beam steering suggests that this sensor can provide the imagery required for crop mapping and monitoring, at a significantly improved revisit schedule. Within the Applications Development Section of the Canada Centre for Remote Sensing (CCRS), the agriculture group has been involved in a multi-year study which includes examining the information content of RADARSAT data for crop type and condition assessment, as well as determining the effects of time of day, environmental conditions and incidence angle on the operational use of RADARSAT data. In particular, this paper examines the separability of crop type based on single and multi-date RADARSAT acquisitions, as well as available visible-infrared imagery. Backscatter responses to crop type and growth stage are discussed in order to optimize RADARSAT acquisitions for crop characterization. As well, preliminary results are provided on the sensitivity of C-HH radar backscatter to crop condition.

Methodology

The site used in this study is centered on the town of Carman ($98^{o}00'$ W longitude, $49^{o}30'$ N latitude), located in southern Manitoba (Canada). Both sandy and heavier clay soils are found across the site and this soil mix is reflected in the diversity of agricultural crops, including canola, wheat, barley, oats, sunflowers, soybeans, corn and flax. CCRS collected a total of 10 standard and fine mode descending RADARSAT images over the Carman area during the months of June, July and August 1997 (Table 1). All available cloud free optical imagery was also acquired and included TM (May 27), SPOT XS (August 6) and IRS-1C PAN (July 4). Hourly meteorological records were used to assess target conditions at the time of image acquisition.

Table 1. 1997 RADARSAT Descending and Optical Data Acquisition Schedule

Date	Acquisition Mode	Incidence Angles
June 28	Fine 2	39-42^o
July 4	IRS-1C PAN	
July 5	Fine 4	43-46^o
July 15	Standard 4	34-40^o
July 18	Standard 1	20-27^o
July 22	Fine 2	39-42^o
July 29	Fine 4	43-46^o
August 5	Fine 5	45-48^o
August 6	SPOT XS	
August 8	Standard 4	34-40^o
August 15	Fine 2	39-42^o
August 22	Fine 4	43-46^o

To characterize field conditions during the 1997 growing season, crop information was collected on July 18-19, 1997 for approximately 300 fields in the Carman area. For each field the information recorded included crop type, phenological stage, crop height and percent crop cover. A photo was also taken at each field to record crop and field conditions. Differential GPS ground coordinates were gathered at road intersections at approximately 1-mile intervals across the study site. Positional accuracies for the GPS model used are well within a RADARSAT pixel (approximately 3-5 metres in the XY direction, 95% of the time). These data were used in the geocoding of the RADARSAT imagery.

During the same week in which general crop information was documented, field crews also collected information on crop growth across 12 pre-selected fields. On each of the 12 fields, transects were planned across the fields, along which sample sites were located. In general, 8-12 sample sites were located in each field. The location of all within-field sample points and treatment locations were also recorded using a differential GPS. At each sample point along the transect, a number of specific measurements and samples were gathered:

(1) Biomass: At each site, a 0.5 x 0.5 m sample of above ground crop was cut and placed in a plastic bag. Biomass samples were weighed wet in the field, and then oven dried and re-weighed. Plant water content (PWC) was calculated using:

$$[(wet\ \ biomass(g) - dry\ \ biomass(g)) / wet\ \ biomass(g)] * 100$$

(2) Leaf Area (LA): A subsample of plant biomass was used to calculate leaf area. LA is recorded in cm^2.

(3) Plant chlorophyll: At each site within a field, 6-10 chlorophyll measurements were made on the canopy's upper leaves using a Minolta spad meter. Measurements were averaged to provide a mean chlorophyll measurement per sample site.

(4) Crop height: At each site, crop height was recorded in cm.

All RADARSAT data delivered for this project contained the most recent antenna pattern correction and payload parameter file which were applied during processing at the Canadian Data Processing Facility (CDPF). Consequently, the data quality and calibration accuracies of this data set are consistent with those reported by Srivastava et al. (1997) (< 1dB relative within scene accuracy). Prior to image interpretation, the CDPF processor applied look up table was removed from all scenes, creating radar brightness (β^o) images. The RADARSAT data were then geocoded using the satellite ephemeris information and a second order cubic convolution resampling algorithm.

Using the information from the crop survey sheets, masks were drawn over selected homogeneous fields and mean power and reflectance values extracted for each field. Mean power/reflectance and standard deviation values were used to calculate the transformed divergence statistic, a measure of crop separability. This statistic has proven to be highly correlated with crop classification accuracies (Haack and Jampoler, 1995).

Results and Discussion

Crop Type Discrimination

Transformed divergence results from only the best three RADARSAT dates, as well as the optical scenes, are presented in Tables 2 and 3. Crops were considered separable if the divergence statistic was greater than 1.5. All acquisitions, except July 18 (S1) were at shallower incidence angles (>35^o) which maximizes interaction with the crop canopy. For the Standard Mode 1 scene, poor separability was observed for all crops except the large broadleaf crops such as corn and canola. This suggests that for all other crop types, contributions to total backscatter may be present from the soil surface when observed at this steep angle. Early in the growing season, the relatively low vegetative cover and significant soil contribution resulted in poor separation among most crops. The exception was canola (June 28) which was separable from barley and corn. Soon after emergence, the canola crop covers most of the soil surface, providing greater interaction of the microwaves with the crop. However, it is not until peak vegetative growth that separability among crops using a single date was notable. In this agricultural region, during late July to early August, crops have completed their vegetative growth period and are now in their reproductive and seed development stage. During this stage, canopy moisture content and canopy structures change dramatically. The enhanced separability of crops at this phenology stage was also reported by Brisco and Brown (1995) for a similar site in the Canadian Prairies.

Table 2. Transformed Divergence Results For Best Three Radarsat Dates

July 22 - Descending

	barley	beans	canola	corn	flax	oats	sunflower
beans	**1.82**						
canola	**1.69**	0.05					
corn	**1.77**	0.01	0.02				
flax	0.04	**1.67**	**1.50**	**1.61**			
oats	0.01	**1.92**	**1.83**	**1.89**	0.08		
sunflower	**2.00**	1.05	**1.61**	1.35	**2.00**	**2.00**	
wheat	0.34	0.77	0.64	0.73	0.18	0.50	**1.90**

Average Divergence: 1.11

August 5 - Descending

	barley	beans	canola	corn	flax	oats	sunflower
beans	1.07						
canola	**1.63**	1.35					
corn	0.48	0.05	0.99				
flax	0.35	**1.98**	**2.00**	**1.91**			
oats	0.19	**1.81**	**2.00**	1.45	0.01		
sunflower	**2.00**	**1.99**	0.10	**2.00**	**2.00**	**2.00**	
wheat	0.07	0.41	0.77	0.09	1.26	0.65	**2.00**

Average Divergence: 1.16

August 8 - Descending

	barley	beans	canola	corn	flax	oats	sunflower
beans	0.87						
canola	1.35	0.62					
corn	0.63	0.00	0.46				
flax	0.43	**2.00**	**2.00**	**2.00**			
oats	0.08	**1.51**	**1.90**	1.34	0.08		
sunflower	**1.80**	**1.55**	0.37	1.25	**2.00**	**1.99**	
wheat	0.05	0.46	0.98	0.30	**1.66**	0.35	**1.56**

Average Divergence: 1.06

Table 3. Transformed Divergence Results For All Optical Channels

August 6 - Channel 1, SPOT

	barley	beans	canola	corn	flax	oats	sunflower
beans	**2.00**						
canola	0.00	**1.99**					
corn	**1.69**	0.45	1.08				
flax	**1.95**	0.07	1.02	0.19			
oats	0.29	0.94	1.25	0.23	0.07		
sunflower	1.17	1.28	0.31	0.63	0.21	0.33	
wheat	0.51	1.02	0.86	0.18	0.09	0.00	0.16
					Average Divergence:		0.71

August 6 - Channel 2, SPOT

	barley	beans	canola	corn	flax	oats	sunflower
beans	**2.00**						
canola	**2.00**	1.03					
corn	**2.00**	0.18	0.98				
flax	**2.00**	0.40	0.40	0.08			
oats	0.72	**1.99**	0.01	1.28	0.41		
sunflower	**2.00**	0.17	0.21	0.59	0.01	1.22	
wheat	**1.99**	**1.69**	0.00	0.39	0.14	0.02	0.55
					Average Divergence:		0.87

August 6 - Channel 3, SPOT

	barley	beans	canola	corn	flax	oats	sunflower
beans	**1.87**						
canola	**2.00**	0.38					
corn	**1.63**	0.01	0.90				
flax	0.25	0.38	**1.99**	0.34			
oats	**1.98**	0.35	**1.84**	1.04	0.00		
sunflower	**2.00**	1.06	0.02	**1.64**	**2.00**	**1.63**	
wheat	**1.88**	0.60	**1.84**	1.37	0.27	0.00	**1.56**
					Average Divergence:		1.10

July 4 - Channel 1, IRS-1C

	barley	beans	canola	corn	flax	oats	sunflower
beans	**1.70**						
canola	**1.99**	**2.00**					
corn	0.43	**1.96**	**2.00**				
flax	0.25	**2.00**	0.68	**1.87**			
oats	0.05	0.19	**2.00**	0.25	1.03		
sunflower	0.01	**1.99**	1.05	1.30	0.03	0.26	
wheat	0.05	**2.00**	1.12	1.39	0.01	0.44	0.00
					Average Divergence:		1.00

When using several RADARSAT acquisitions during the late July to early August time period, almost all crops were separable based on their backscatter responses. Spring wheat, however, was the exception. Brisco and Brown (1995) also reported poor separability of grain crops and suggested that this was due to the very similar structure among the various grain classes. For the data presented here, it appears that the difficulty is also related to the large variability in backscatter responses associated with the spring wheat class. In referring to field notes and photographs, wheat crops across the site were in various stages of growth including vegetative growth, heading, lodging and senescing. These variations are primarily a result of slight differences in planting dates.

Later in the growing season, differences in backscatter among cereal crops are reduced as all grain crops senesce and are harvested. Separability of broadleaf crops declined and may be related to the saturation of the signal as the crop canopies are fully developed.

In examining the transformed divergence statistics from the SPOT and IRS-1C images, barley was the only grain crop which could be separated from all other crops. In early August, the barley crops are almost completely senesced, producing a significantly different visible-infrared signature. Other grain crops are slightly behind in their growth stage relative to barley. A significant amount of confusion exists among broadleaf crops. Only corn and canola were separable using SPOT's near-infrared band. Although crop structure is changing during this reproductive stage, most crops still have significant chlorophyll content and remain green. The IRS-1C image, acquired earlier in the season, was able to resolve some of those classes confused in the SPOT image. However, corn was still confused and grain crops could not be separated.

A single RADARSAT acquisition (either July 22 or August 8) provided better discrimination than a single channel of SPOT or the July 4 IRS-1C. The best three RADARSAT scenes occurred in the late July/early August time period (July 22, August 5 and August 8). This compares well with Brisco and Brown (1995) who found that the highest multi-date crop classification accuracy for C-HH, was associated with June 24, July 21 and August 10. Using these 3 dates, the authors were able to classify crops to a 72% overall accuracy.

Crop Condition

In examining the RADARSAT and IRS-1C imagery collected over several of the intensively sampled fields, significant within-field variability was detected for a number of the image acquisitions. Visual interpretation of the images using field observations suggests that the RADARSAT imagery does detect differences in soil attributes during periods of low vegetative growth and differences in crop growth during more advanced growth stages. The IRS-1C PAN imagery tended to provide better boundary definition of these within-field differences.

Although visual inspection of imagery collected over these fields has suggested that crop condition information may be contained in both the radar and the optical data, more rigorous quantification of these relationships is required. To accomplish this, site crop parameters were regressed against backscatter coefficients. Each radar image was first filtered using a 3x3 median filter to reduce speckle effects. Then, at each sample site within the field, mean backscatter coefficients were extracted for a 6x6 pixel window centered on the site. The mean backscatter coefficients were then regressed against several crop parameters (height, biomass, plant water content and leaf area) using a backwards linear regression approach. Only independent variables significantly contributing to explained variance within the multivariate model (at $p < 0.05$) were retained. To increase sample numbers, fields of similar crop type were pooled during the regression. Initially, analysis has focused on the imagery acquired close to the date of field sampling and currently correlations have been generated only for the radar data. Three crop types have been examined, including wheat, canola and potatoes.

Table 4. Multivariate Correlation Results

Date	Significant Variables Included in Model	Correlation Coefficient (R)*
Wheat (N = 24)		
July 15 (S4)	Biomass, plant water content	0.757
July 18 (S1)	---	NS
July 22 (F2)	Height	0.546
Canola (N = 19)		
July 15 (S4)	Biomass, plant water content	0.789
July 18 (S1)	---	NS
July 22 (F2)	Height, plant water content, LA	0.647
Potatoes (N = 42)		
July 15 (S4)	Height, plant water content	0.700
July 18 (S1)	Biomass, plant water content	0.549
July 22 (F2)	Height	0.689

* significant at probability < 0.05
NS = not significant

Preliminary regression results suggest that variations in indicators of crop vigor are reflected in variations in radar backscatter (Table 4). As expected, imagery collected at steep angles (July 18) provides limited or no information on crop condition. Significant contributions from the underlying soil at these angles explain these poor results. At shallower angles (> 35^o), several crop variables, particularly biomass, plant water content and height are significantly related to backscatter. The best results are reported for the July 15 image, although for canola and potatoes, results for the image acquired a week later are similar. Senescence of the wheat crop may explain the poorer results as the acquisition date moves further into the growing season. For the July 15 image, results were slightly better for the wheat and canola crops since with a more continuous crop cover, less soil contributions are occurring. Differences in results between July 15 (Standard 4, 4-look) and July 22 (Fine 2, 1-look) may also be related to the difference in number of looks. Plant water content was important in explaining backscatter variations, in addition to an indicator of crop growth (biomass or height). Using only a single RADARSAT acquisition during the period of peak biomass, between 50-60% of the variation in backscatter can be explained by crop variables. Although the remaining unexplained variance will be related to a number of factors, soil contributions may still be a factor given the RADARSAT configuration (C-HH).

Although these initial results are encouraging, further work is required to explore backscatter correlations with crop parameters throughout the growing season, as well as correlations between crop parameters and SPOT/IRS-1C reflectance. Also, in the work presented here, independent variables removed from the model were described as statistically insignificant given the presence of other variables in the model. Some investigation is required to establish whether one or two crop variables can consistently explain backscatter variance. As well, the separability of crop type using three bands of SPOT data relative to three dates of RADARSAT data will be assessed.

Conclusions

As part of the Canada Centre for Remote Sensing's project to evaluate the use of RADARSAT for crop type and crop condition mapping, this paper reported on the separability of crop type using single-date and multi-date RADARSAT and optical data. The best separabilities were observed when crops were in the process of seed development. A single RADARSAT image acquired during the period of crop reproduction is better able to differentiate crops relative to a single SPOT XS channel acquired during the same period. Multi-date RADARSAT and optical data appear to improve discrimination of crops, although separating spring wheat remains difficult. Results from this study support those previously published, although this study extends the application of SAR for crop mapping from airborne and ground-based platforms to RADARSAT. Preliminary statistical analysis and visual interpretation of a number of intensively sampled fields suggests that radar data does provide some information on indicators of crop condition. During the period of peak growth, both plant water content and an indicator of crop growth (biomass or height) provided significant correlations with backscatter. The analysis of crop condition assessment using the Carman data set will expand to include other SAR and optical acquisitions as well as other crop types. In addition, during the 1998 growing season, CCRS acquired quad-polarized airborne data and will be working to examine the added information content for crop characterization using this configuration, in preparation for RADARSAT-2.

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