Incidence Angle Considerations for Crop Mapping Using Multitemporal RADARSAT Data

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Abstract - **In order to effectively use multidate RADARSAT data for agricultural crop monitoring, the implications of combining datasets from different RADARSAT modes, and thus with varying incidence angles, must be addressed. As part of the Canada Centre for Remote Sensing's Agriculture-ADRO project, 3 dates of RADARSAT imagery were acquired within a one week period, over a site in Manitoba Canada. Incidence angle dependent backscatter changes were examined as a function of crop type, and a simple first order correction for incidence angle is proposed.**

1. INTRODUCTION

A number of agricultural remote sensing applications, including crop monitoring, require frequent repeat satellite coverages particularly during critical temporal periods. In the past, the infrequent revisit schedule of earth observation satellites, compounded with the obstruction of data collection as a result of cloud cover, has impeded the use of satellite data for agricultural mapping and monitoring. The flexibility associated with RADARSAT's beam steering and the all weather capability of radar data collection suggests that RADARSAT can provide the imagery required for crop mapping, at a significantly improved revisit schedule. For Canadian latitudes, standard beam mode images can be acquired at a 3 day revisit schedule. However, to accomplish this, data must be acquired at different incidence angles.

The incidence angles associated with RADARSAT's seven standard beam modes and fifteen fine modes range from approximately 20° (steepest angle) to approximately 50° (shallowest angle). Numerous research studies have demonstrated that incidence angle is a significant first order sensor parameter effecting backscatter from earth surface targets. In agriculture, backscatter associated with soil moisture, surface roughness and vegetation interactions have all proven to be incidence angle dependent (Daughtry *et al*., 1991; McNairn *et al*., 1996; Poirier *et al*., 1988). Correlations between backscatter and surface volumetric soil moisture are greatest at steeper incidence angles while the relationship between soil surface roughness and backscatter is strongest at shallower angles (McNairn *et al.*, 1996). Two other sensor parameters - frequency and polarization - are also critical in determining backscatter from agricultural crops. Lower frequencies penetrate further into the crop canopy, interacting with lower canopy structures, as well as the soil surface. Vertically polarized waves tend to couple more with the vertically aligned stalks of agricultural crops (Brisco *et al*., 1990).

For agricultural crops, incidence angle determines the parts of the canopy which are the dominant contributors to backscatter (Daughtry *et al.*, 1991). In addition, the contribution of the underlying soil surface to total backscatter is incidence angle dependent. Although incidence angle is a component in all radar applications research (ie. Bouman and van Kasteren, 1990), Poirier *et al*. (1988) directly addressed incidence angle effects on backscatter from crop canopies. Poirier *et al*. (1988) reported that the vegetation has more effect on backscatter at $\theta = 53^o$ than at $\theta = 30^o$. Consequently, the researchers concluded that backscatter collected at shallower incidence angles provided better overall classification accuracies for crops. Daughtry *et al*. (1991) confirmed that at shallower angles, most of the scattering was originating from within the crop canopy and that very little of the backscattering signal originated at the soil surface. These relationships are dependent on crop type and crop growth stage.

To effectively use multidate RADARSAT data for agricultural monitoring, the implications of combining datasets with varying incidence angle characteristics must be addressed. The Canada Centre for Remote Sensing (CCRS) initiated a study to quantify the change in

RADARSAT backscatter associated with agricultural crops, as a function of incidence angle and crop type. The preliminary results of this study are presented in this paper, along with a proposed simple first order correction factor for incidence angle.

2. METHODOLOGY

The site used in this study is centered on the town of Carman (98°00’ W longitude, 49°30’ N latitude), located in southern Manitoba, Canada. The site covers an area of approximately 10 km (north-south) by 30 km (east-west). Both sandy and heavier clay soils are found across the site and this soil mix is reflected in a diversity of agricultural crops including wheat, barley, oats, canola, corn, sunflowers, beans, peas and potatoes.

As part of the CCRS Agriculture ADRO project, a total of 16 standard and fine mode descending and ascending RADARSAT images were acquired over the Carman area during the months of June, July, August and September 1997. Several optical images were also acquired and these include: June 28 (TM - Bands 3,4,5), July 1 (SPOT XS) and July 11 (TM - Bands 3,4,5). Of the entire ADRO dataset, three descending RADARSAT acquisitions occurred within a single week, during the period of peak crop growth. These acquisitions included July 15 (Standard 4), July 18 (Standard 1), and July 22 (Fine 2). The incidence angles at the centre of the site for these 3 acquisitions were approximately 37°, 24° and 41°, respectively. No precipitation occurred during acquisitions and it was assumed that crop developmental changes during the 7 day period would be minimal. A trace amount of precipitation (approximately 1 mm) occurred the day before the first acquisition, and two days before the second, but as a result of high maximum daily temperatures, it is unlikely that this small amount of rainfall had any significant impact on backscatter at the time of acquisition.

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. Using the Omnistar 7000, DGPS (differential gps) ground coordinates were gathered at road intersections at approximately 1-mile intervals across the study site. Positional accuracies for this GPS model 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.

All RADARSAT data delivered for this project have had the most recent antenna pattern correction and payload parameter file applied during processing at the Canadian Data Processing Facility. Consequently, the data quality and calibration accuracies of this dataset are consistent with those reported by Srivastava *et al*. (1997). Prior to image interpretation, the processor applied look up table was removed from all 3 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. Each image was then registered to a field boundary vector map. RMS resampling errors were within a pixel. Using the information from the crop survey sheets, masks were drawn over selected fields and mean power values extracted for each field. Class average power values were then converted back to dB.

3. INCIDENCE ANGLE COMPARISONS

For the main crop types found in the site, average backscatter was plotted as a function of incidence angle (Fig. 1). Although only 3 data points are used, Fig. 1 demonstrates the strong dependence of backscatter on incidence angle, for all crop types. The dependence of backscatter on incidence angle can be grouped into two classes. Broadleaf crops, in particular beans, canola and sunflowers, appear to have a simple linear dependence on angle. For grain crops (barley, oats and spring wheat), a significantly greater change in backscatter per degree is evident between 36° (July 15) and 42° (July 22). Ground observations during the field campaign (July 18-19) indicated that grain crops were in the reproductive stage (heading and milk stage). It is therefore likely that the larger reduction in backscatter from grain crops between the July 15 and July 22 acquisitions is a combination of incidence angle effects, as well as crop phenology changes (Bouman, 1991; Brisco *et al*., 1992).

Using class average backscatter values from the three images, estimates of the change in backscatter per degree of incidence ($\Delta\sigma^o/\theta^o$) were made for each crop type (Fig. 2). Due to the limited number of data points and the limited range in incidence angles, the calculation of a more rigid quantitative model for angle correction was not possible. However given this limitation and assuming a linear relationship, when all crops were considered as a single class, there was a corresponding 0.32 dB change in backscatter per degree of change in angle. Changes in backscatter with angle were lowest for broadleaf crops when compared to grain crops. Also, rates of change were less between the July 15 ($\theta = 37^o$) and July 18 ($\theta = 24^o$) images although this observation is likely attributable to the crop phenology changes discussed previously. In October of 1996, RADARSAT data were acquired over bare soil surfaces in Altona, Manitoba. Soil moisture conditions were relatively stable during the acquisition period. In comparing changes in backscatter from 20^o to 50^o, Pultz (1998, personal communication) reported that backscatter changed by about 0.28 dB per degree for bare soil surfaces.

Assuming that crop phenology changes were less for the broadleaf crops, the linear dependence of backscatter on incidence angle for sunflowers was used as a basis for a simple first order backscatter correction (0.26 dB change per degree). In Fig. 3, this factor has been applied to all crop classes. The correction compensates well for the first image pair (24-37^o) and for all broadleaf crops. The residual reduction in backscatter for grain crops between 37^o and 41^o is likely associated with a change in backscatter attributable to changes in the growth stage of the grains during the acquisition period.

4. CONCLUSIONS

Collection of 3 dates of RADARSAT imagery (incidence angles ranging from 24^o (Standard 1) to 41^o (Fine 2)) over an agricultural region in Manitoba Canada, confirmed the dependence of crop backscatter on incidence angle. When combining RADARSAT imagery acquired in different modes, these angular effects must be removed if meaningful target information is to be extracted for the purposes of agricultural monitoring. Based on the limited data set presented here, when all crops were considered as a single class the average change in backscatter per degree was 0.32 dB. Grain crops tended to have a slightly higher rate of change compared to broadleaf crops, although heading and in-filling of the grain crops at the time of the study may explain this observation. Although for operational monitoring care must be taken to separate target changes from incidence angle effects, this study demonstrates that the application of a simple correction factor can compensate for some incidence angle effects.

5. REFERENCES

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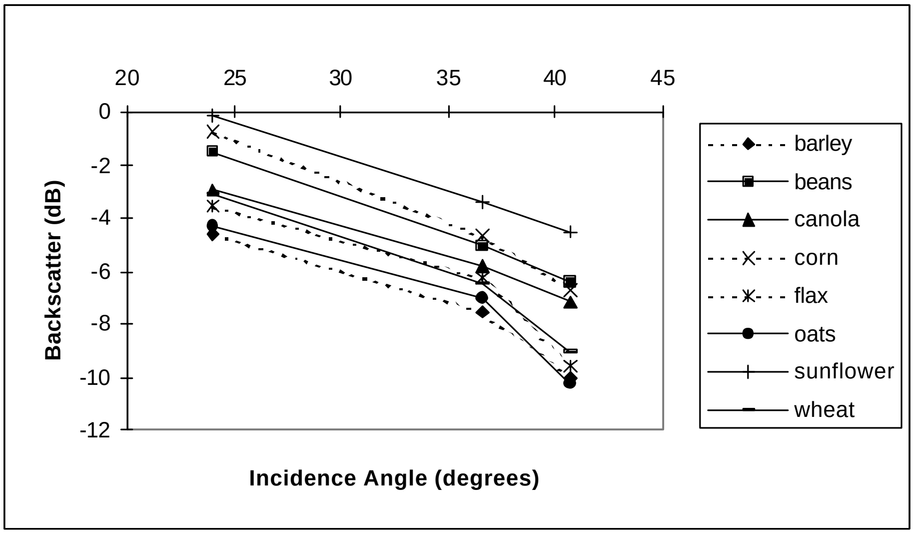

Fig. 1. Backscatter as a Function of Incidence Angle

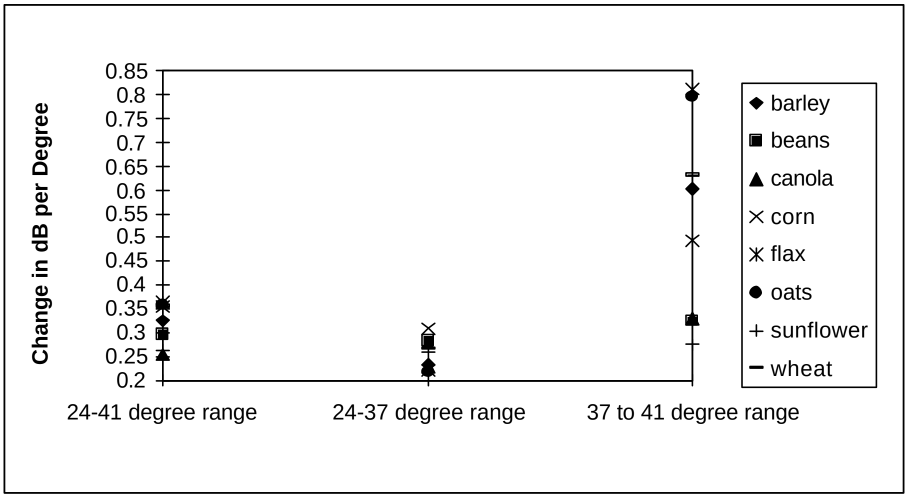

Fig. 2. Changes in Backscatter Per Degree of Incidence Angle

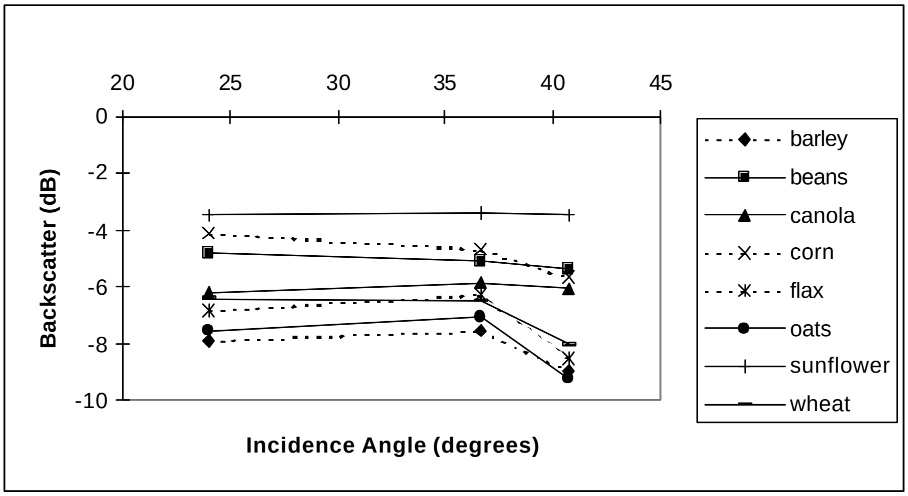

Fig. 3. Incidence Angle Correction