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Using RADARSAT-1 for Crop Monitoring: Choosing Between Ascending and Descending Orbits

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Abstract – **Radar sensors, like RADARSAT-1, can be a valuable tool for monitoring agricultural crops. RADARSAT-1 imagery can be acquired regardless of cloud cover, and the satellite can be programmed to collect imagery in a wide range of beam modes and incidence angles. This flexibility significantly increases the revisit schedule thereby ensuring that images can be acquired during key crop growth stages. Users also have the flexibility of choosing acquisitions during either ascending or descending orbits. However, the condition of agricultural targets can change diurnally and as a result, care must be taken in choosing between RADARSAT-1's dawn and dusk orbits. In temperate regions, early morning dew is often present on the crop canopy at the time of the satellite overpass. Consequently, this study used fine mode dawn/dusk image pairs acquired over western Canada to examine the potential effect of dew on operational crop mapping. The data consistently demonstrated that backscatter increased when dew was present on the canopy. However, overall crop separability did not appear to be affected by the presence of dew. These results indicate that although choice of orbit is less important for crop classification, the probability of dew on the canopy must be carefully considered when users are extracting quantitative crop information from radar imagery.**

1. INTRODUCTION

In agriculture, the condition of soils and crops changes diurnally, from day to day, and throughout the growing season. The dynamic nature of crop growth means that crop monitoring is particularly challenging. Imagery acquired from orbiting satellites offers a tremendous opportunity to track temporal changes in crop condition and to map crop type over large areas. However, the success of crop mapping and monitoring with remotely sensed imagery depends, to a great extent, on ensuring that imagery is acquired during key stages of crop growth development.

Synthetic Aperture Radars (SARs) record the amount of microwave energy scattered back to the sensor by the target. RADARSAT-1 transmits microwaves at a frequency of 5.3 GHz. These frequencies are able to penetrate cloud cover and are thus capable of acquiring information on the target regardless of cloud cover. It is clear that since reliable data delivery is essential in agricultural monitoring, SAR has an important role to play. However, microwave interactions with the target are complex. Thus, if meaningful information is to be extracted from the data, users must carefully select the beam modes, incidence angles and orbital configurations best suited for their application.

In the microwave region of the electromagnetic spectrum, it is the large-scale structure and dielectric properties of the target that influence the radar backscatter. It is accepted that increases in target moisture results in an increase in radar backscatter. For example, Allen and Ulaby (1984) noted that the presence of water on leaves changed the dielectric properties of the target. As a result backscatter response increased relative to radar return under normal dry conditions. Sofko *et al*., (1989) also observed significant increases in radar backscatter from a wheat canopy following a rain event. Rain on the canopy increased backscatter by 2-4 dB.

It is unclear, however, whether surface wetness affects crop type separability. Gillespie *et al*., (1990) concluded that water on the canopy may enhance or degrade crop type separability, depending on several factors: the way in which water is held on plant parts, on the source of moisture (dew or rain), and sensor parameters such as wavelength, polarization, and look angle. In evaluating the effects of free canopy water on SAR crop separability, Brisco *et al.,* (1989) and Fischer *et al.,* (1992) found that the separability between certain grain classes was enhanced under wet conditions. However, Fischer *et al.* (1992) noted a decrease in total crop separability.

With the option of acquiring RADARSAT-1 imagery at dawn (approximately 6:30 AM local time), the effect of dew on the canopy must also be evaluated. Few studies have addressed the impact of dew on SAR backscatter. However, Brisco *et al.,* (1993) hypothesized that the formation of dew on the crop canopy likely has a similar effect on backscatter as rainfall. This observation follows from a study by Gillespie *et al.,* (1990), where data from a truck mounted scatterometer suggested that the presence of dew on wheat could be detected at steeper incidence angles (20°). In this study, backscatter increased by 2-4 dB when dew was present on the wheat canopy.

This paper presents the results of a study in which backscatter from ascending (dusk) RADARSAT-1 acquisitions was compared to backscatter recorded 12 hours later, on a descending (dawn) pass. The only significant target change between these two acquisitions is the presence of dew on the crop canopy during the descending pass. With three ascending/descending pairs, the effect of dew on the absolute backscatter was evaluated. Crop separability statistics were also generated to evaluate whether crop type discrimination was affected by the presence of canopy dew. These results have important implications for the use of RADARSAT-1 imagery for operational crop monitoring.

2. DATASETS AND METHODOLOGY

RADARSAT-1 imagery was acquired over a study site located in the Red River Valley of southern Manitoba (Canada) (figure 1). Four ascending/descending image pairs were collected in 1997 (table 1). Imagery was acquired at about 6:30 PM (local time) during an ascending orbit. Approximately 12 hours later an image was acquired at dawn, during a descending pass.

The land use and economy of the site is based on intensive and diversified agricultural production. Agricultural crops grown across the site include a variety of cereal grains, canola, corn, sunflower, flax, and soybeans. The local topography ranges from very flat in the west to gently rolling hills in the east. Soils type changes from sandy loam in the west to heavier clays in the east. An inventory of crop type was collected on about 300 fields in July of 1997. In addition to crop type, crop height, growth stage and row direction was recorded for each field.

Daily meteorological summaries for the Carman weather station (approximately centred in the study site) were supplied by the Winnipeg Climate Centre. The daily meteorological summaries included maximum and minimum temperature and amount of precipitation. For the August 14/15 image pair, rain occurred over the site during the image acquisitions. Consequently, this pair is not used in the analysis presented here. To determine the probability of dew formation, hourly relative humidity, dew point, and minimum temperature were recorded from midnight to 7 AM at the Carman weather station (table 2). Both temperature and relative humidity were recorded at a height of 1.5 metres. At crop level during the night Gillespie *et al*. (1990) noted that temperature is cooler and relative humidity is higher, increasing the probability of dew formation. Bullock (1997) stated that when the minimum temperature and dew point are within half a degree of each other conditions are conducive for the formation of dew on the crop canopy. Shaded cells in table 2 indicate the likely on set of dew formation.

The RADARSAT-1 imagery was processed at the Canadian Data Processing Facility (CDPF). This processing included application of the Payload Parameter File corresponding to the acquired imagery. This file contains the antenna elevation gain pattern that is applied during processing to reverse the illumination variation that occurs during imaging. The image quality and calibration of these data are expected to be consistent with those reported by Srivastava et al. (1999); a relative radiometric accuracy of better than 1.0 dB.

Prior to image analysis, the digital number values were converted to radar brightness (β^o) by reversing the application of a Look Up Table. This Look Up Table had been applied just prior to the data transfer to CD-ROM in the CDPF. The RADARSAT-1 data were then geocoded using the satellite ephemeris information, ground control points with positions obtained using a differential GPS, and a second order cubic convolution resampling algorithm.

Masks were drawn over selected homogeneous fields and field average power was calculated. Approximately 10 fields of each major crop type were used. Within each crop class, fields that were chosen had crops at the same growth stage. Field average power values were then converted to radar brightness (β^o). Radar brightness is defined as the mean radar reflectivity per unit pixel area and the calculation of β^o does not require any knowledge of the local incidence angle (Raney *et al.*, 1994).

In order to determine the impact of dew on crop type separability, a divergence statistic was calculated which provides a measure of between class separability (Swain and Davis, 1978):

$$Div = 0.5 * (\overline{\chi}_i - \overline{\chi}_j)^2 * \left(\frac{1}{\sigma_i^2} + \frac{1}{\sigma_j^2} \right) + \frac{1}{2} \left(\frac{\sigma_i^2}{\sigma_j^2} - 2 + \frac{\sigma_j^2}{\sigma_i^2} \right) \qquad [1]$$

where Div is a measure of separability between two crop classes. $\overline{\chi}_i$ and $\overline{\chi}_j$ represent the crop mean and σ_i and σ_j, the standard deviation for crop types *i* and *j* respectively. In order to minimize the domination of class pairs with large divergence, calculation of a transformed divergence (T.D) has been adopted here:

$$T.D. = 2 * [1 - \exp(\frac{-Div}{8})] \qquad [2]$$

3. RESULTS AND DISCUSSION

Average backscatter values for each of the major crop type classes are illustrated in figure 2. Each graph displays one image pair, the first acquired at approximately 6:30AM (descending) and the second at approximately 6:30 PM (ascending). Error bars indicate the variability in backscatter within each crop class.

Meteorological data reported approximately 5 mm of light rainfall two days prior to the June 27 and 28 image acquisitions. With mean daily temperatures for this period above 20°C and night time lows between 10°C and 15°C, no rain would be present on the canopy at the time of the image acquisitions. Dew point data recorded around the time of the descending acquisition indicated that conditions were favourable for dew formation sometime between 3AM and 5AM. Dew would still be present on the canopy at the time of the satellite overpass. Dew forms as very tiny droplets in an almost continuous film over the leaves, especially in the upper third of the canopy. Comparing the dawn and dusk orbits, average backscatter was significantly higher during the descending acquisition. On average, backscatter was 2.5 dB higher during this dawn acquisition when dew was present on the canopy.

A heavy dew occurred on the morning of July 22 as indicated by the dew point data in table 2. The air was saturated from midnight (July 21) to 7 AM indicating the strong probability of dew formation during this time. Only trace amounts of rain were recorded throughout the week prior to the two image acquisitions with mean daily temperatures greater than 20°C. As with the first image pair, an increase in backscatter is observed on the early morning image, for all crops. Relative to the first image pair, the differences in backscatter between the dawn/dusk pair is slightly less, only 1.7 dB.

Recorded weather data for the period prior to the August 21 and 22 image acquisitions indicated trace amounts of rainfall two days prior to the overpasses. However, daily temperatures approached a high of 25°C and therefore, the canopy was considered dry at the time of the dusk acquisition. Again the dew point data confirmed that conditions were favorable for the formation of dew between midnight (August 21) and 7 AM. On average, backscatter was 1.8 dB greater for fields examined on the dawn acquisition. Incidence angle differences between these two image pairs were small. A significant variability in backscatter within crop classes is illustrated in figure 2. Crop growth stages are variable at this point in the growing season as seed development continues and senescence begins.

Backscatter decreases as incidence angle increases. Therefore, image pairs were chosen to minimize differences that might be attributed to incidence angle. Nevertheless, some differences in angle do exist between the ascending and descending images. In comparing the two July acquisitions, the descending acquisition has a shallower incidence angle (Fine 4) relative to the ascending acquisition (Fine 3). In this particular case, this small incidence angle effect would in fact act to reduce dew effects observed on the dawn image. In contrast, the incidence angle differences for the June image pairs is larger (Fine 2 and Fine

5). Since the dawn acquisition has a steeper angle, the difference in incidence angle may compound backscatter differences that result from the presence of dew on the canopy.

In general, changes in backscatter from the ascending to the descending passes were similar among the various crop types. However, for the July image pairs, canola showed very little difference when field average backscatter from the two acquisitions were compared. Field observations indicated that many of the canola plants were beginning pod development. As pods form, leaf surface area decreases and could decrease the presence of dew on the canopy.

The increase in backscatter that results when dew forms on crop canopies prior to early morning acquisitions suggests that care must be taken if imagery is being used to extract quantitative crop condition information. However, it is also important to determine if the presence of dew effects crop separability. When comparing the three image pairs, broadleaf crops like sunflowers, potatoes, soybeans and corn generally showed greater changes in backscatter when dew was present on the leaves. This is likely related to the larger surface upon which dew can form.

Transformed divergence statistics were run on the three image pairs and results are given in table 3. Bolded values in table 3 identify where divergence numbers differed by more than 0.5 when comparing the dawn and dusk acquisitions. Although some differences in divergence are noted, on average the differences in crop type separability are small when comparing results from the ascending and descending images. The divergence tables also indicate that, in general, crop discrimination using a single RADARSAT-1 image is poor. As described by McNairn *et al.* (2000), crop discrimination requires the use of multiple RADARSAT-1 images acquired throughout the growing season.

The results presented in figure 2 support the conclusion that in general, the presence of dew on the canopy does not appear to increase or decrease crop separability. Rain tends to form a much less continuous water cover, sitting in discrete drops and catching in leaf whorls, along midribs etc. Since crop structure varies, the pattern of rain on the canopy would also vary. This could explain why some researchers have found that crop type discrimination is affected by rainfall (Gillespie *et al*., 1990). Since dew forms more of a film on the leaves, it appears to have less of an effect on crop discrimination.

A simple linear regression was used to test whether, as suggested in figure 2 and table 3, relative differences in backscatter from one field to the next remained the same regardless of whether the canopy was dry or was dew covered. Results in table 4 were produced by regressing individual field average backscatter recorded on the descending pass, against field average backscatter from the ascending pass. Backscatter between the ascending and descending orbits was highly correlated. This result suggests that although absolute backscatter increased in the presence of dew, relative differences remained very similar. In figure 3, class average backscatter over all dates is presented. As with the correlations for each individual image pair, class average backscatter recorded on the ascending passes are highly correlated with class average backscatter from the descending passes (R-value of 0.941). It is clear from the regression results that although backscatter from the crops was higher during the early morning acquisitions, relative class differences were maintained.

4. CONCLUSIONS

Results from the analysis of three pairs of ascending and descending images, acquired approximately 12 hours apart, indicated that the formation of dew on the crop canopy does effect radar backscatter. In these particular comparisons, backscatter from crops on which dew had formed, was 1.7 to 2.5 dB greater when compared to acquisitions 12 hours earlier when dew was not present on the crops. This observation suggests that users should be careful in combining ascending and descending orbits when extracting quantitative crop information from RADARSAT-1 imagery. If imagery from these orbits are combined, it may be difficult to separate dew effects from other changes in the target. In temperate regions where the probability of afternoon rain is less, evening acquisitions would avoid possible dew effects. Nevertheless, this study demonstrates the importance of always acquiring meteorological data to characterize target conditions during image acquisitions.

Results also indicated that dew on the crop neither increases nor decreases crop separability. This suggests that for crop type mapping, choice of orbit is less important. Flexibility in the choice of orbits thus increases the number of potential image acquisitions.

5. REFERENCES

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Table 1.
List of RADARSAT-1 Acquisition Dates Over Southern Manitoba

Date	Orbit	Beam Mode	Incidence Angle	Acquisition Time	Meteorological Conditions Prior to Descending Acquisition
June 27, 1997	Ascending	F5	45-48°	6:32 PM	
June 28, 1997	Descending	F2	39-42°	6:40 AM	Dew present
July 21, 1997	Ascending	F3	41-44°	6:32 PM	
July 22, 1997	Descending	F4	43-46°	6:40 AM	Dew present
August 14, 1997	Ascending	F5	45-48°	6:32 PM	Rain during acquisition
August 15, 1997	Descending	F2	39-42°	6:40 AM	Rain during acquisition
August 21, 1997	Ascending	F3	41-44°	6:28 PM	
August 22, 1997	Descending	F2	39-42°	6:36 AM	Dew present

Table 2.
Meteorological Conditions Prior to Descending Overpasses

Dew point	*Hour after Midnight (00)*							
Date	*00*	*01*	*02*	*03*	*04*	*05*	*06*	*07*
June 28, 1997	12.9	12.6	11.3	11.3	10.3	11.2	12.6	11.5
July 22, 1997	16.4	16.3	16.3	15.2	15	15.2	16.1	16.7
August 22, 1997	12.4	11.7	11.3	10.4	9.2	8.8	8.1	10.3

Minimum Temperature	*Hour after Midnight (00)*							
Date	*00*	*01*	*02*	*03*	*04*	*05*	*06*	*07*
June 28, 1997	16.7	15.3	13.1	11.9	10.6	11.5	14	17.6
July 22, 1997	16.4	16.3	16.5	15.4	15	15.2	16.1	16.7
August 22, 1997	13	11.9	11.3	10.4	9.2	8.8	8.1	10.3

Table 3.
Transformed Divergence Results for Ascending and Descending Image Pairs

ASCENDING ORBITS

June 27, 1997

Transformed Divergence

	Canola	Wheat	Corn	Sunflower	Potato
Wheat	0.609				
Corn	1.319	0.011			
Sunflower	0.201	0.494	0.786		
Potato	0.562	0.058	**0.078**	0.263	
Beans	0.886	0.010	0.001	0.530	0.037
			Average Divergence		0.390

July 21, 1997

Transformed Divergence

	Canola	Wheat	Corn	Sunflower	Potato
Wheat	**1.844**				
Corn	0.399	1.121			
Sunflower	**0.180**	1.985	1.104		
Potato	0.071	1.880	0.433	0.714	
Beans	0.175	1.599	0.109	0.806	0.091
			Average Divergence		0.834

August 21, 1997

Transformed Divergence

	Canola	Wheat	Corn	Sunflower	Potato
Wheat	1.007				
Corn	0.004	0.933			
Sunflower	0.463	1.919	0.631		
Potato	0.271	0.169	0.245	1.510	
Beans	0.178	0.264	0.157	1.366	0.008
			Average Divergence		0.608

DESCENDING ORBITS

June 28, 1997

Transformed Divergence

	Canola	Wheat	Corn	Sunflower	Potato
Wheat	0.753				
Corn	1.705	0.087			
Sunflower	0.427	0.269	0.948		
Potato	0.757	0.137	**0.645**	0.060	
Beans	1.104	0.042	0.374	0.233	0.059
			Average Divergence		0.507

July 22, 1997

Transformed Divergence

	Canola	Wheat	Corn	Sunflower	Potato
Wheat	**1.062**				
Corn	0.002	0.996			
Sunflower	**1.242**	1.947	1.261		
Potato	0.486	1.779	0.532	0.637	
Beans	0.031	1.268	0.047	1.058	0.284
			Average Divergence		0.842

August 22, 1997

Transformed Divergence

	Canola	Wheat	Corn	Sunflower	Potato
Wheat	0.975				
Corn	0.026	1.416			
Sunflower	0.726	1.981	0.443		
Potato	0.165	0.311	0.415	1.582	
Beans	0.085	0.448	0.266	1.397	0.011
			Average Divergence		0.683

Table 4.
Regression Results Based on Correlation Between Ascending and Descending Orbits

	Correlation Coefficient	n	Regression Equation
June 27 and June 28	0.872*	53	$\sigma^o_{DSC} = 4.888 + 1.215 * (\sigma^o_{ASC})$
July 21 and July 22	0.918*	52	$\sigma^o_{DSC} = 2.140 + 1.058 * (\sigma^o_{ASC})$
August 21 and August 22	0.914*	51	$\sigma^o_{DSC} = 1.749 + 0.996 * (\sigma^o_{ASC})$

* statistically significant at probability of less than 0.001

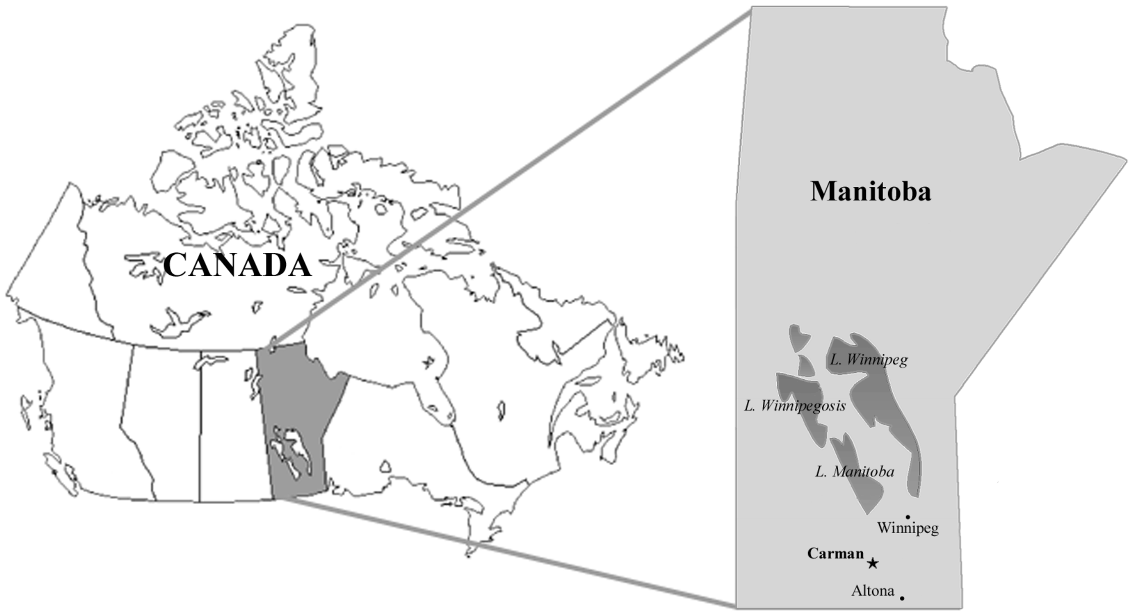
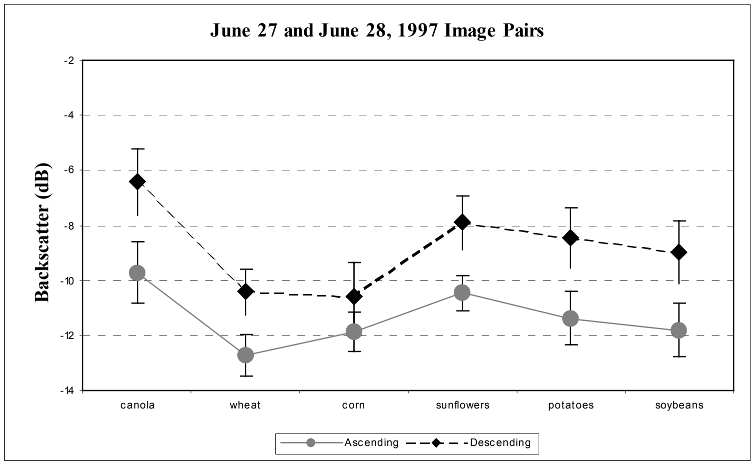
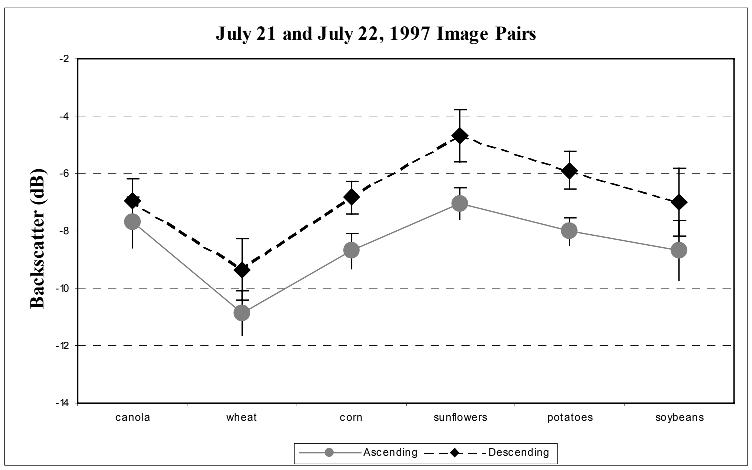


Figure 1. Location of the study site. The ascending and descending image pairs were centred on town of Carman, Manitoba, located south-west of Winnipeg





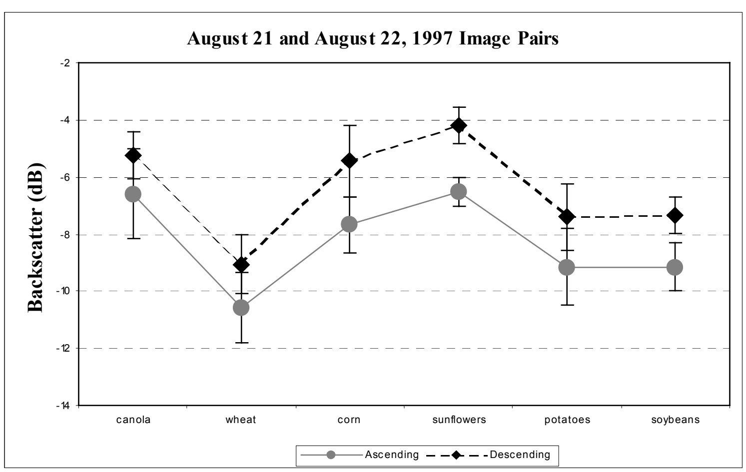


Figure 2. Class average backscatter associated with the ascending and descending RADARSAT-1 image pairs. In these graphs, average backscatter is presented for each crop class. The variation in backscatter within each class is indicated by the error bars.

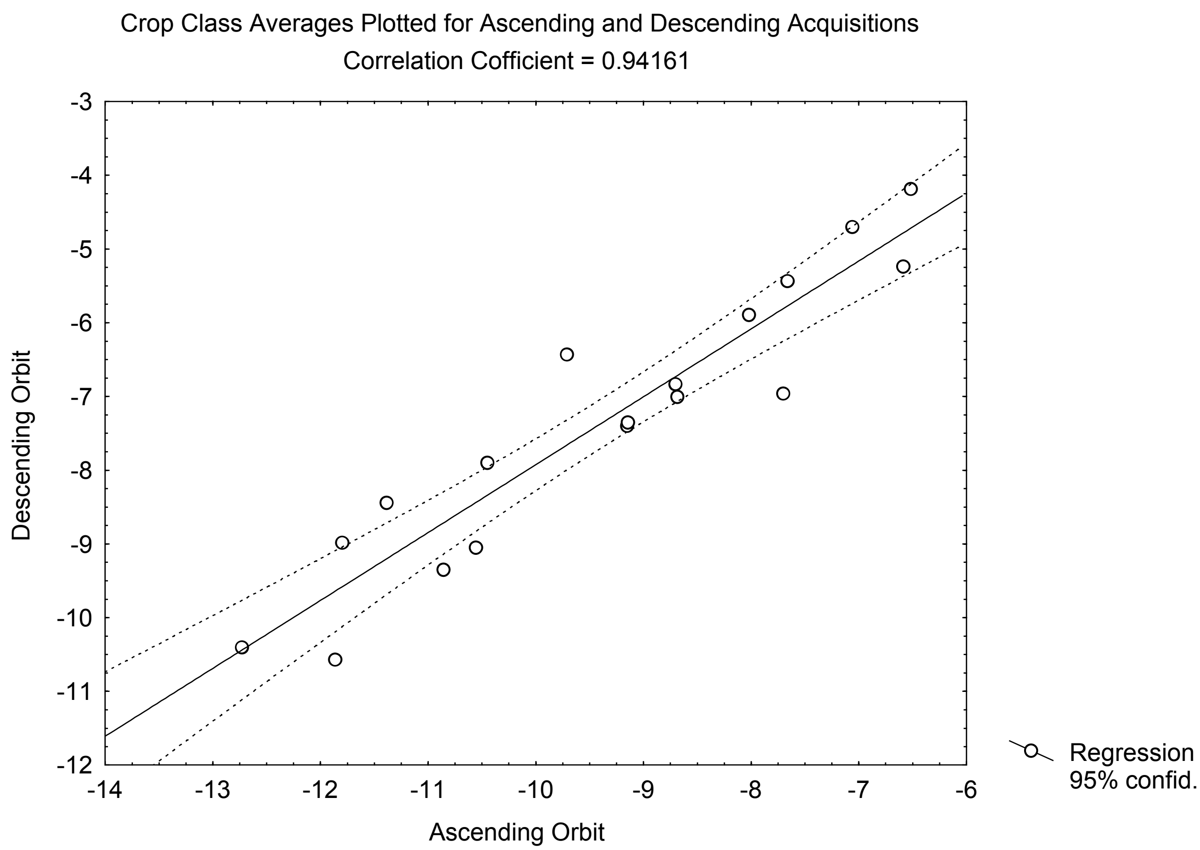


Figure 3. Results from correlation of class average backscatter recorded on the three ascending and three descending RADARSAT-1 acquisitions. The regression coefficient (R = 0.941) clearly demonstrates that although absolute backscatter was affected by the presence of dew, the relative backscatter among the crop classes was similar.