RADARSAT backscatter from an agricultural scene

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Abstract

Orbital remote sensing in the microwave electromagnetic region has been presented as an important tool for agriculture monitoring. The satellite systems in operation have almost all-weather capability and high spatial resolution, which are features prominent for agriculture. However, for full exploitation of these data, an understanding of the relationships between the characteristics of each system and agricultural targets is necessary. This paper describes the behavior of backscatter coefficient $\sigma^0$ derived from calibrated data of Radarsat images from an agricultural area. It is shown that in a dimensionless diagram of $\sigma^0$ there are three main regions in which most of the crops can be classified. The first one is characterized by low backscatter values, with pastures and bare soils. The second one has intermediate backscatter coefficients and comprises various crops mainly, and a third one, with high backscatter coefficients, in which there are heads with strong structures exhibit a kind of double bounce effect. The results of this research indicate that the use of Radarsat images is optimized when a multiemisoral analysis is done making the best use of the agricultural calendar and of the dynamics of different cultures.

Index terms: remote sensing, radar, land use, farmland.

Retrosesalimentamento de uma cena agrícola em imagens de radar

Resumo

A baixa espectral das microondas tem uma importância para o sensoramento remoto agrícola, por ser uma área em que se tem uma maior certeza de disponibilidade de imagens de satélite, independentemente das condições atmosféricas. Entretanto, embora mais sensíveis em operação na baixa do radar, o aproveitamento desses usos ainda não é amplamente utilizado, principalmente em virtude da falta de estudo de sensibilidade às características que ocorrem entre o radar e os alvos agrícolas. Neste trabalho, são utilizadas três mesas de Radarsat para analisar os valores de retroescalonamento $\sigma^0$ representativos das diversas condições dos talhões agrícolas em uma região intensamente cultivada. Através de uma estimação dos valores de $\sigma^0$, pode-se verificar a existência de três regiões de um caracterizada por baixos valores, e constituída por solo exposto, a sequência, com valores intermédios, e constituída por culturas desenvolvidas, e uma terceira, com altos valores de retroescalonamento, constituída por superfícies muito ruídosas, particularmente quando os sucos de milho são remanejados a direção de visada do satélite. Os resultados deste trabalho indicam que o uso de imagens Radarsat para agricultura e mais otimizado quando se faz uma análise multiemisoral, aproveitando o calendário agrícola e a dinâmica das diferentes culturas.

Termos para indexação: sensoramento remoto, uso da terra, terras agrícolas.

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INTRODUCTION

Orbital remote sensing data have been available since the early seventies, and are based mainly on optical systems, e.g., Landsat and SPOT satellites. These systems have granted many useful data for crop monitoring, crop area and yield estimation (Nuggli-Kamto et al., 1999), and detection of important crop

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variances (Tribusano et al., 1997). However, the use of optical remote sensing in large scale for agricultural monitoring is hindered by cloud cover, rain and in most of tropical countries. In these countries more than 80% of the crop production come from the summer growing season, when the cloud cover is thinner.

Radar remote is the unique sensor that can provide data independently of cloud cover, rain and season, and has been playing a very important role in the study of vegetation. However, the nature of radar interaction with targets is quite different from that of optical signal. Geometric and electrical properties of targets are very important in radar waveforms (Lewis et al., 1994), while physical and chemical properties are important in optical regions. Nevertheless, as the radar and optical properties of interaction with targets are distinct, there is a clear complementarity between these two data sources.

With the new orbital radar systems available last years (ERS - European Remote Sensing Satellite. JERS - Japan Earth Resources Satellite. and KALMAR) there was an increase in studies trying to combine radar data into agricultural remote sensing programs (Tribusano & Brown, 1998). In order to fully exploit the radar data as a useful source of data for agriculture it is necessary to understand the interactions between radar signal and the crop varieties along its development in the field.

Thus, the main objective of this paper is to characterize and discuss the general pattern of the backscattering signal in a scene with various types of agricultural land uses, and to investigate the multitemporal behavior of backscattering signal activated from some specific field conditions from Kalmar images.

The backscattering coefficient (σ°) is an important parameter to be acquired in radar images. As explained by Joost et al. (1995), the σ° is the result of: (1) geometric factors - related to the surface attributes of targets, and (2) of electrical factors - related to dielectric properties of soil and vegetation cover, for a given wave length. The geometric factors can be divided into macro and microtopography. The macrotopography relates to the terrain topography or relief and it affects the signal that comes from a large region of the terrain. The microtopography of the roughness is more related to the particular conditions of a specific field, e.g. the soil surface condition, of the leaf and plant arrangements (Morgan et al., 1998). The electrical factors are influenced by the dielectric properties of the elements that constitute the area of terrain illuminated by the radar beam. In this sense, the soil and plant relations to water may an important role in the backscattering signal.

When the sensor system is considered, Tribusano & Brown (1998) indicate that frequency, incidence angle and polarization are the main factors that influence target signal sensed in the microwave region. In addition, there are the spatial resolutions in azimuth and range, the beam width, and the power of transmitted pulse.

Specifically for vegetation, Udaya et al. (1998) point out six main factors that influence the radar backscattering: (1) the dielectric constant of the vegetation material; (2) the size of canopy, and the size of elements, like leaves, twigs, stems and flowers; (3) the shape and orientation of canopy elements; (4) the roughness of canopy elements; (5) the geometry of the soil cover, including row direction, row spacing, percent ground cover, and plants height). Most of these factors are discussed in looks (1999).

Cron discrimination is an important task in any crop monitoring system. Tribusano & Udaya (1998) used radar data in multiple frequencies and dual polarization in a multitemporal basis and demonstrated the new potential of such a data for crop classification. Terrazzone et al. (1991) tested three microwave frequencies and dual polarization in a crop classification scheme and found that the band L and C could improve the discrimination within agricultural areas. In addition, the availability of polarimetric data allowed a significant improvement in land classification.

Soares et al. (1999) were able to discriminate seven agricultural classes in Brazil using the added texture measures in L and C radar images with three polarizations. Isi & Martin (1999) used multitemporal classification of LRS-1 SAR images for agricultural targets, and could find accuracies better than 10%.
Kadarsat-1 is a platform with a C-band radar launched by Canada in 1992. Some of its main features are the possibilities for user to choose the incidence angle, the operation mode, and the spatial resolution. The main Kadarsat features are in Table 1. The possibility of changing the incidence angle allows the temporal revisit interval to change, thus increasing the monitoring capabilities.

**Material and Methods**

Cron development is a dynamic process. Different crops present individual characteristics of development. In many cases, these differences are used in agricultural remote sensing to extract information on crop type and crop stage. In addition, in tropical countries, the cron calendar is not very rigid because it is dependent on the weather conditions and on the rain and soil moisture conditions for the plants. In remote sensing, it is to be efficiently used for crop monitoring, such differences in cron development have to be explored. Since radar data can be acquired in any cloud condition, the full temporal resolution of the system can be explored, and thus various images can be acquired during the cron growing season. Indeed, in order to follow the development of a test site it is necessary to gather as many images as possible (Liew et al., 1998).

Kadarsat acquisition program is useful for monitoring the changes in the vegetation. However, in this study, the incidence angle and other acquisition parameters were maintained the same. Thus, three images in mode 2 were 29 (48.5 to 32.6 incidence angle) were acquired in a consecutive orbit over the test site: January 3th, February 24th and March 20th, 1999. With these three images, a multitemporal analysis of the scene containing agriculture fields was accomplished.

The test site was at Sumare, Sao Paulo State, Brazil (coordinates 22°55' to 22°48'5 and 41°20' to 41°21' W). Different land uses can be found in this area. The main uses are with agriculture. The cron calendar is flexible: when the images were acquired, it could be found the rice, soybean, sugarcane, cotton, corn, tomato fields, and pasture, mainly. The rain was monitored, and in January, one day before the image acquisition there was a rain of 40 mm rainfall. Two days before the February acquisition the rainfall was 19.6 mm, and in March there was no rainfall at least five days before Kadarsat image acquisition. In addition, the day was strong in February. All the images were varied during the three radar image acquisition dates, and data such as cron type, stage, height, row direction, and soil surface condition were acquired. Another kind of data used in this work were 35-mm low altitude aerial photographs, which were acquired at the same days as the Kadarsat image acquisitions. These photographs helped the network and allowed making a fast and detailed description of the fields. Actually, in this kind of research it is difficult to obtain a systematic sampling of targets in the same condition. For instance, usually it is hard to find a number of sugarcane fields at the same phenological stage and same row direction. Thus, it was tried to encompass

**Table 1. Kadarsat main features.**

<table>
<thead>
<tr>
<th>Feature</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>5.3 GHz</td>
</tr>
<tr>
<td>Wavelength</td>
<td>5.6 cm (C band)</td>
</tr>
<tr>
<td>Polarization</td>
<td>HH</td>
</tr>
<tr>
<td>Incidence angle</td>
<td>10° to 60°</td>
</tr>
<tr>
<td>Range resolution (ground range product)</td>
<td>8-100 m</td>
</tr>
<tr>
<td>Azimuth resolution (ground range product)</td>
<td>8-100 m</td>
</tr>
<tr>
<td>Nominal temporal resolution (repeat cycle)</td>
<td>24 days</td>
</tr>
<tr>
<td>Swath</td>
<td>50-500 km</td>
</tr>
<tr>
<td>Orbit</td>
<td>Sun-synchronous, quasi-polar, circular</td>
</tr>
<tr>
<td>Inclination</td>
<td>98.6°</td>
</tr>
<tr>
<td>Altitude</td>
<td>798 km</td>
</tr>
<tr>
<td>Antenna size</td>
<td>15 x 1.5 m</td>
</tr>
<tr>
<td>Operation modes</td>
<td>Standard, wide, fine, scan-sar, extended</td>
</tr>
</tbody>
</table>

Source: Liew et al. (1998)
most of the crop and/or soil conditions in order to represent most of the patterns of backscatter backscattering and type of interactions with agricultural scenes.

For the quantitative analysis, P.A.L software (P.A.L, 1997) was used, and the $\sigma$ values were extracted, in order to accomplish this step, the original data were calibrated and then transformed to intensity values. For each field, a large number (from 120 to 1,000 pixels) of the backscatter intensity values, in gray levels, were extracted and the mean, standard deviation and standard error of the mean were calculated. The conversion to backscatter in dB values ($I_{dB}$) was performed using the following relationship (Crispke et al., 1995):

$$I_{dB} = 10 \log_{10} \frac{I_{ref}}{}$$

where $I_{ref}$ is the mean of each sample in gray levels extracted from the intensity image.

In addition, the confidence intervals were calculated using the equation 2, according to DeRoo (1993) adapted to radar:

$$10 \log_{10} \frac{I_{ref}}{\sigma_{I}} = 10 \log_{10} I_{dB} \pm 2 \sigma_{I}$$

where $I_{ref}$ is the mean backscatter in dB values for each field sample, $\sigma_{I}$ is the number of pixels in each sample, and $\sigma_{I}$ is the standard deviation. Additional details about the image processing can be found in Crispke et al. (1999).

Profiles of the mean and standard error of the mean of the $\sigma$ were derived for various fields in order to analyze the relationships between agricultural land use and the general pattern of the backscatter data.

RESULTS AND DISCUSSION

The agricultural scene is composed of various types of agricultural areas. In this work, the main agricultural areas were grouped into three soil types: black soil (BS), black loam soil (LBS), yellow loam (YL), white loam (WL), savanna (SA), corn (C), soybean (S), rice (R), beans (B), and cotton (C). Among these, yellow loam is the most representative of the agricultural area used in this study.

In order to derive the quantitative relationship between the backscatter coefficient and the various types of agricultural areas, an analysis of distribution of backscatter values for each field was performed. These results are shown in Figures 1, 2, and 3 for January, February, and March, respectively. The spectral distribution of the backscatter values generates a curve with three distinctive regions. The first region is characterized by low backscatter values, but with strong negative correlation (acoustic-like curve). The second region is a positive linear-like with very low incidence and intermediate of $\sigma$ values, and the third region is a flat positive exponential-like curve with higher $\sigma$ values. The same general pattern is found for the three season images.

Each of these regions groups together fields with specific characteristics. The first region groups the areas with very low backscatter values, which are bare soils, pastures, low flow areas, and some other areas. In general, this region presents fields with backscatter values lower than 11 dB. If the soil surface is smooth, such as when it is prepared for grain seeding, it can be considered a smooth surface for radar signals. However, there is a condition of soil surface that must be considered. Some crops need a special trowel, such as carrots, if these carrots are smooth, the surface is smooth irrespective of the smoothness of the trowel. If the trowel is not deep (trowel needs), for example, then the surface becomes rough. In addition, the trowel needs are nearly parallel to the radar viewing direction, the surface tends to seem smooth in radar image. On the other hand, if the trowel needs are perpendicular to the radar viewing direction, the surface becomes very rough, making the backscatter very strong and thus making that need to be brighter in the radar image. The low densities, even if they are not very deep, are seen by radar as relatively smooth surfaces, indicating the influence of the underlying soil and are relatively dark in radar images. These results are in accordance with Pinho et al. (1999), when evaluating the effect of trowel roughness on land backscatter coefficient for three radar frequencies. These situations can be illustrated by the cases and in the figure 4.

The second region (Figures 1 to 3) is characterized by intermediate backscatter values, typically between -11 and -7 dB. This region includes most of the fields with agricultural vegetation, such as corn and soybean, or even lower densities and even lower fields within the test site. The surface roughness as seen by radar in this region is intermediate and presents similar values. In general, these fields...
Figure 1. Backscattering values for each field in January. Letters indicate the use: B (bean), BS (bare soil), CS (corn), CT (cotton), T (tillage field), P (pasture), SC (sugar cane), T (tomato), TS (tilled soil). Vertical bars indicate the standard error of the mean.

Figure 2. Backscattering values for each field in February. Letters indicate the use: B (bean), BS (bare soil), CS (corn), CT (cotton), T (tillage field), P (pasture), SC (sugar cane), T (tomato), TS (tilled soil). Vertical bars indicate the standard error of the mean.

Present a vegetation height greater than 0.5 m and are well homogenous. When the vegetation is well developed, the radiation that reaches the canopy is partially scattered and partially extinguished inside the canopy, giving rise to intermediate backscattering values. In fact, in a study with corn, Ulaby et al. (1984) analyzed the backscattering coefficients in function of the leaf area index (LAI) and concluded...
Figure 3. Backscattering values for each field in March. Letters indicate the use: d (bean), bs (bare soil), cc (corn), ct (cotton), f (fallow field), p (pasture), sc (sugarcane), t (tomato), ts (tined soil). Vertical bars indicate the standard error of the mean.

Figure 4. General backscattering model for a radar agricultural scene.
that most of the LAI values (between 0.3 and 2) were in the -1.5 to +1.5 dBs interval.

In the third region of the backscattering dissonance diagrams (Figures 1 to 3) groups exhibit high backscattering values higher than +1.5 dBs. These areas are considered ground in the radar L frequency region (see case in Figure 4) generating high backscattering signals. In this region there were located mainly bare soil areas with a high density ofarda or sand, which are similar to the radar viewing direction. These areas were located for tomato in general, these areas produce the same double bounce effects (Wisler et al., 1991). These effects are caused by a combination of radar beam direction and the orientation of the features resulting in main returns towards the radar sensor. The same effect was observed for the small cotton field located in the test site. This field was planted perpendicular to the radar viewing direction also. Moran et al. (1998) also found the returns and their directions in cotton fields as well as the radar backscattering signal. In cotton, this double backscattering signal produces a wave-like effect on the radar image. However, for this specific field it is difficult to evaluate all the factors affecting the backscattering signal. In short, Figure 4 depicts a general backscattering model to explain a complex agricultural scene.

From these analyses it is clear that these broad backscattering regions are quite noticeable in radar images. In addition, this pattern is consistent with the three radar scenes in different dates. It is supposed that this pattern can be followed as a rule. If this is true, it could be used in a classification scheme as a first step to categorize the scene. Then, each specific region should be analyzed in detail in order to extract information on specific fields. For instance, the second region (Figures 1 to 3), which has most of the growing crops, there was not found a clear pattern that could be used to discriminate corn from a hybrid. However, if the crop calendar is explored, it could be possible to use the usual backscattering patterns inside this region for this kind of separation. This leads to a clear statement that the use of radar data in agriculture has not been done in a multitemporal context.

Conclusions

1. Radar agricultural scenes present a clear pattern for the backscattering signals.

2. The pattern can be divided into three main regions: one of low backscattering values (around -2 dBs or lower), a second one with intermediate values (from -1.5 to +1.5 dBs), and a third one with high values (higher than around +0 dBs).

3. The first region comprises smooth surfaces as measures, bare soil, and very low fields; the second one is composed of intermediate smooth to rough surfaces as corn, sunflower, and the main crops; and the third region is composed of rough surfaces of many structured features, like soil tillage or with deep furrows perpendicular to the radar beam direction, some crops like cotton, and small field features. For the best exploration of radar data for agriculture it is important to follow the crop calendar. This is highly recommended in multitemporal acquisitions of satellite radar data.

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