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This study investigated the effects of sugarcane-planting row directions in the HH- and VV-polarized, ALOS/PALSAR imageries. Twenty sugarcane fields from São Paulo State, Brazil, were classified into rows parallel and rows perpendicular to the range direction of the satellite. Backscattering coefficients (σ°) from 10 images were analyzed. For HH polarization, σ° values from fields with perpendicular rows were higher than those from parallel rows (~1.2 dB). For HV polarization, there was no statistically significant difference. Therefore, HV-polarized PALSAR images are preferable for producing maps of cultivated areas with sugarcane or to discriminate sugarcane varieties, among other applications.

Keywords: synthetic aperture radar (SAR); sugarcane; row directions; L-band

Introduction

Although optical remote-sensing images are often used for agricultural monitoring (e.g., Fortes and Demattê 2006; Abdel-Rahman and Ahmed 2008), they present restrictions in regions with persistent cloud cover. Moreover, optical data are related only to the top millimeters of a canopy, and the effects of solar illumination and solar azimuth angle need to be taken into consideration. An alternative is to use synthetic aperture radar (SAR) data because they can obtain images of the Earth's surface regardless of cloud cover conditions (Paradella et al. 2005; Radarsat-2 2013); moreover. it presents very high synergies with optical remote sensing (Jiaguo et al. 2004). Another advantage of SAR sensors is the possibility of data acquisition in four different polarization modes – (HH (horizontal transmit and horizontal receive), HV (horizontal transmit and vertical receive), VH (vertical transmit and horizontal receive), and VV (vertical transmit and vertical receive)) – which allows better target discrimination and image classification (Yun et al. 1995; McNairn and Brisco 2004; McNairn, Hochheim, and Rabe 2004).

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Spectral signatures of sugarcane (*Saccharum spp.*) in the microwave region are still poorly understood because of a limited research. One exception is the work of Baghdadi et al. (2009) and Baghdadi, Todoroff, and Zribi (2011), who concluded that the data obtained by L-band and HH- and HV-polarized SAR systems from areas planted with sugarcane in Reunion Island, east of Madagascar, were highly correlated with height measurements. They also reported a strong correlation between the HH-polarized backscatter coefficient (σ°) and the normalized difference vegetation index (NDVI) derived from the maturation and harvesting stages. At the maturation phase, the σ° values presented a sharp decline related to the decrease of the plant water content. Haraguchi et al. (2010) have used Palsar data in monitoring sugarcane crop during its vegetative cycle, but there were no findings of a relationship between a backscatter and the crop parameters such as plant height, density, and leaf numbers. Lin et al. (2009), studying sugarcane plantations in Guangdong Province, China, noticed a high correlation between leaf area index (LAI) and C-band HV/HH-ratioed σ°. They highlighted the importance of image analysis obtained in the seedling and maturation stages. In these phases, the σ° values from sugarcane fields were highly distinct from the σ° of the surrounding targets.

Other studies have emphasized the use of L-band data because of their close relationship with plant biomass (Brisco et al. 1992; Pampaloni et al. 1997; Baghdadi et al. 2009). Paloscia (1998), by analyzing the performance of C-, L-, and P-band σ° values to estimate the LAI of wheat, corn, and alfalfa, concluded that the best results were obtained by the L-band data with a HV polarization. Significant differences in σ° were reported by Paris (1983), Moran et al. (1998) and Silva et al. (2009) in studies involving soy, corn, cotton, coffee, potato, carrot, beet, onion, and wheat with different planting row directions. This study aimed to understand the influence of sugarcane-planting row directions in the L-band and HH- and HV-polarized ALOS/PALSAR imageries.

Materials and methods

Study area

The study area comprised sugarcane fields in the northeastern region of São Paulo State, in the municipalities of Dobrada and Guariba (between 20° 28′ and 21° 38′ south latitude and between 48° 13′ and 48° 22′ west longitude), near the municipalities of Jaboticabal (north) and Araraquara (southeast). The climate is tropical. According to the 1971–2000 climatological time series, January to March are the wettest months (607 mm on average), and January and February are the hottest months (24.3°C on average). July to September are the driest months (118.2 mm on average), and June is the coolest month (18.6°C on average) (UNESP 2011). The elevation ranges from 500 to 800 m, while the slope varies from zero to 8% (Oliveira et al. 1999). Oxisols are the dominant soil type in the region (Martorano et al. 1999).

The study area represents more than 35,000 hectares of sugarcane of 23 varieties with early (harvesting in April and May), intermediate (harvesting in May to July), and late (harvesting in July to September) growing cycles. Early varieties can have either 12-month (year sugarcane) or 18-month (year-and-a-half sugarcane) growing periods. After the first harvest, the cycle reaches 12 months, after which it is called ratoon sugarcane or stubble crop. The same crop can be harvested five to seven times (Rudorff et al. 2010). The appropriate variety is chosen based on local biophysical conditions (soil, climate, and plant characteristics). According to Prado et al. (1998) and Prado (2005), areas for sugarcane cultivation are often classified into five categories – from A (best situation) to E (worst situation).

This research considered only plots with the RB86-7515 variety because it was the most representative in the study site. This variety presents a rapid growth rate, a tall canopy, a strong upright growing trend, a high density of stems, a dominant purple-green color, and an intermediate growing cycle. The variety is also drought tolerant and has a high saccharose content and high productivity (Hoffmann et al. 2008).

Database

Ten ALOS/PALSAR images from February, May, August, and October of 2007, 2008, and 2009 were acquired for this study (Table 1). The PALSAR sensor is an L-band SAR with three different observation modes, namely, polarimetric, fine beam and ScanSAR, with varying viewing angles, spatial resolutions, and swath widths (Igarashi 2001). The images analyzed in this study presented the following modes: 1.5G processing level, ascending, fine beam dual (FBD, HH, and HV polarizations, pixel size of 12.5 m), and fine beam single (FBS, HH polarization, pixel size of 6.25 m). All images were acquired with an incidence angle of 38°.

PALSAR images were preprocessed to correct for radiometric and geometric effects. The radiometric correction involved the conversion of digital amplitude values to backscattering coefficients (σ°, units in decibels (dB)) (Shimada et al. 2009) (Equation (1)). According to Rosenqvist et al. (2007), this conversion optimizes the analysis of multitemporal radar images from a given site.

$$\sigma^{\circ} = 10 * \log(\mathrm{DN}^2) + \mathrm{CF}, \tag{1}$$

where DN = digital number; CF = calibration factor (Table 2).

Table 1. Characteristics of ALOS/PALSAR images analyzed in this research.

Overpass	Acquisition mode	Number of looks
19 February 2007	FBS	2
22 August 2007	FBD	4
7 October 2007	FBD	4
22 February 2008	FBS	2
8 April 2008	FBS	2
24 May 2008	FBD	4
24 August 2008	FBD	4
9 October 2008	FBD	4
24 February 2009	FBS	2
27 August 2009	FBD	4

Note: FBS = fine beam single mode, FBD = fine beam dual mode.

Table 2. Calibration factors of PALSAR images.

Acquisition mode	Up to 8 January 2009 (dB)	After 9 January 2009 (dB)
FBS HH	−83.4	−83.0
FBD HH	−83.2	−83.0
FBD HV	−80.2	−83.0

Source: AUIG (2009).

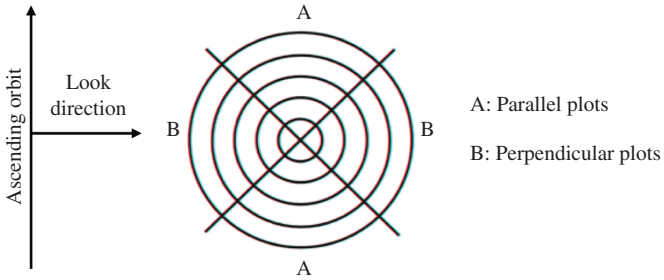

Figure 1. Diagram used to classify sugarcane plots into parallel and perpendicular to the sensor's look direction.
Source: Adapted from Silva et al. (2009).

The geometric correction of the PALSAR images was conducted based on the Landsat ETM+ GeoCover image acquired on 23 March 2001, and available at the website of the University of Maryland, USA (http://glcf.umiacs.umd.edu/data/landsat/). The images were registered to the UTM projection system, the WGS84 datum and the 23S time zone.

A set of 20 plots was classified as parallel or perpendicular to the sensor's look direction (Figure 1). This classification was based on 5-m equidistance contour lines of the study area (1:10.000 scale) provided by the Bonfim Mill and derived from an ALOS/VNIR image (spatial resolution: 10 m) obtained on 8 February 2008, and from a QuickBird optical image available in the Google Earth™ program (overpass: April 2008). The time differences between the PALSAR, AVNIR, and QuickBird overpasses were considered negligible, as the sugarcane plots were planted in 2004 and remained in the field for at least five years.

Mean σ° values were calculated for the plots presenting the planting of rows parallel and perpendicular to the direction of the emitted SAR signals. To better understand the temporal behavior of the backscatter signals from sugarcane plantations, was analyzed precipitation data. The precipitation is directly related to the soil moisture content and is one of the surface parameters that strongly influence the intensity of backscattered energy. These data were provided by the Bonfim Mill group. The average σ° values from the planting rows perpendicular and parallel relative to the sensor look direction were analyzed statistically using a non-parametric Mann-Whitney test (Mann and Whitney 1947) at significance level of 5%.

Results and discussion

Ten plots were classified as having parallel planting rows and 10 as having perpendicular rows. The relative distance between the planting rows was 1.4 m at the beginning of the cycle for the perpendicular-viewing plots. The relative distance between plants in the same line was approximately 0.2 m at the beginning of the season for the parallel-viewing plots (Figure 2). These distances tended to decrease as the sugarcane grew and clumps increased.

For HH polarization, the mean σ° values for the perpendicular plots were 0.7–2.3 dB higher than those from parallel plots. For HV polarization, there was no difference in σ° values at a significance level of 5%. Wegmüller et al. (2011) also noted that the planting row directions found in potato, carrot, beet, onion and wheat crops had an influence on SAR signals obtained by HH and VV polarizations, but not by HV or VH polarizations.

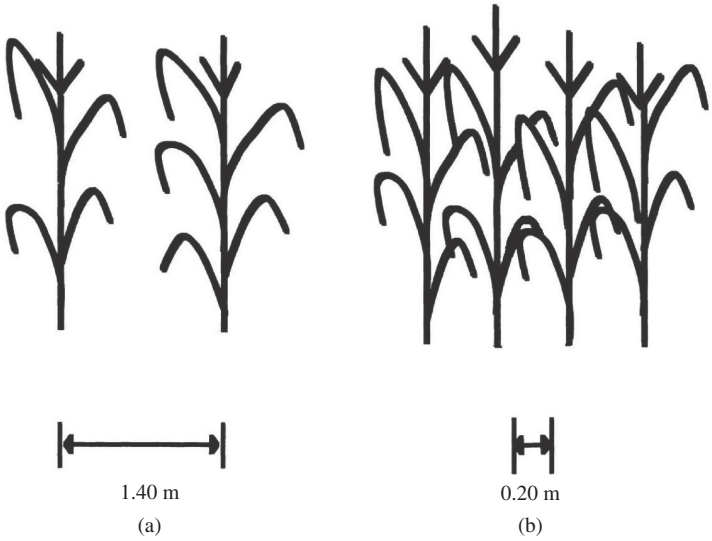

Figure 2. Average spaces between sugarcane planting rows (a) and between plants in the same row (b).

HV-polarized data are more closely correlated with LAI or biomass, as noted by Paloscia (1998) and Simões, Rocha, and Lamparelli (2005).

The mean σ° values for the plots planted with parallel and perpendicular rows and precipitation data are shown in Figure 3, because the relations of soil and plant to water play an important role on the backscattering signal (Formaggio, Epiphanio, and Simões 2001). In the image acquired on 9 October 2008 (10 months of the growing cycle), we would expect lower σ° values because of the maturation phase of the plant and the dominant dry conditions at this time of year. However, the rainfall accumulated by October 8 was relatively high, at 43 mm (Figure 3). This rainfall accumulation may have caused an increase of the dielectric constant of the plant, consequently increasing the σ° values. For the image acquired in February 2009 (two months of the growing cycle),

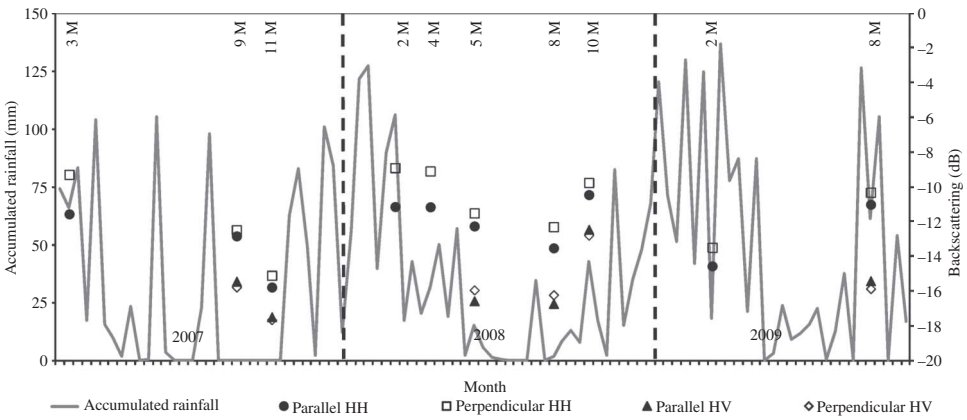

Figure 3. Mean σ° from the sugarcane plots, and rainfall data from the study area.
Note: M – month.

Table 3. A Mann–Whitney test was used to compare sugarcane's plots parallel and perpendicular to the satellite's look direction ($\alpha = 0.05$) and the descriptive summary statistics (mean and standard deviation).

Satellite overpass	Polarization	Age of plant (months)	Parallel plots (μ and σ)	Perpendicular plots (μ and σ)	*P*-value
19 February 2007	HH	3	−11.56 (σ = 0.62)	−9.29 (σ = 0.56)	0.0002
22 August 2007	HH	9	−12.83 (σ = 0.66)	−12.48 (σ = 0.92)	0.5966[a]
22 August 2007	HV	9	−15.45 (σ = 0.96)	−15.78 (σ = 1.54)	0.2121[a]
7 October 2007	HH	11	−15.78 (σ = 1.02)	−15.11 (σ = 1.44)	0.3847[a]
7 October 2007	HV	11	−17.49 (σ = 1.25)	−17.66 (σ = 1.95)	0.3256[a]
22 February 2008	HH	2	−11.15 (σ = 1.18)	−8.91 (σ = 0.91)	0.0013
8 April 2008	HH	4	−11.16 (σ = 0.59)	−9.10 (σ = 0.68)	0.0002
24 May 2008	HH	5	−12.26 (σ = 0.66)	−11.51 (σ = 0.58)	0.0376
24 May 2008	HV	5	−16.57 (σ = 0.87)	−15.94 (σ = 0.86)	0.1121[a]
24 August 2008	HH	8	−13.52 (σ = 0.53)	−12.30 (σ = 0.73)	0.0028
24 August 2008	HV	8	−16.72 (σ = 0.72)	−16.22 (σ = 0.98)	0.2413[a]
9 October 2008	HH	10	−10.46 (σ = 0.54)	−9.77 (σ = 0.50)	0.0091
9 October 2008	HV	10	−12.46 (σ = 0.97)	−12.80 (σ = 0.76)	0.3913[a]
24 February 2009	HH	2	−14.56 (σ = 0.40)	−13.50 (σ = 0.63)	0.0039
27 August 2009	HH	8	−11.02 (σ = 0.55)	−10.32 (σ = 0.40)	0.0145
27 August 2009	HV	8	−15.42 (σ = 0.98)	−15.87 (σ = 0.72)	0.5636[a]

Note: [a]Not significant at 5%.

however, the plots showed low $\sigma°$ values because of a dry spell event that occurred near the time of the satellite overpass. The results indicate a strong influence of accumulated rainfall of backscatter, seeing that the $\sigma°$ values are directly related to the soil water.

The effect of the planting rows in the HH-polarized PALSAR data was noticed until the eighth month of age (Table 3). In the image acquired in October 2008 (10 months of age, average plant height of approximately 3.5 m), the $\sigma°$ values from the parallel plots were similar to those from the perpendicular plots, probably because sugarcane was already completely covering the soil surface.

Overall, the plots with young plants (two or three months of age) were more sensitive to the effects of the planting rows because of the characteristics of the plant management (Figure 4). The backscatter values from the perpendicular plots were higher than those

(a) (b) (c)

Figure 4. PALSAR HH-polarized image from 22 February 2008 (a), QuickBird optical image available in the Google Earth™ program from April 2008 (b) and a PALSAR HH-polarized image from 8 April 2008, (c) overpasses. Parallel plots are outlined in red, and perpendicular plots are outlined in green. The image scene is 2.9 km.

Figure 5. Panoramic field photo obtained on 14 May 2010, illustrating a typical directional terrain roughness found in the study area after sugarcane harvesting.

from the parallel plots. After a mechanical harvesting, the straws are left on the soil surface (~10 cm thickness) to prevent the development of shoots. After approximately seven days, the straws start to clump, forming windrows along the planting rows. This type of management leads to a succession of small clumps with a height of approximately 15–20 cm aligned along the row direction, increasing the terrain's directional roughness (Figure 5) and, consequently, increasing the σ° values, especially for the perpendicular plots. This result may have occurred because the sugarcane plants are regularly spaced in the range direction and are aligned with the wave fronts. Thus, the reflection of each plant will contribute coherently with the reflection of the other scatterers. This phenomenon is known as Bragg scattering. The same finding was also obtained by Formaggio, Epiphanio, and Simões (2001).

Conclusions

The results indicate that in some cases there are statistical differences between L-band σ° values. These differences are caused by the effects of different planting row directions (parallel and perpendicular to the sensor's look direction). These differences need to be taken into account, for instance, in works aiming to discriminate sugarcane varieties and to estimate sugarcane productivity from SAR data.

HH polarization was more influenced by the planting row direction than HV polarization, mainly for aged plants (>eight months). To obtain more accurate maps of sugarcane plantations or to monitor sugarcane productivity, we recommend giving preference to HV-polarized images. As an ongoing research, we recommend designing and validating specific image processing techniques that have the potential to reduce planting row effects in the HH-polarized ALOS/PALSAR imageries.

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References

Abdel-Rahman E. M., and F. B. Ahmed. 2008. "The Application of Remote Sensing Techniques to Sugarcane (Saccharum spp. Hybrid) Production: A Review of the Literature." *International Journal of Remote Sensing* 29 (13): 3753–3767.

AUIG (Alos User Interface Gateway). 2009. PALSAR: Calibration factor updated. Accessed June 8, 2009. https://auig.eoc.jaxa.jp/auigs/en/doc/an/20090109en_3.html

Baghdadi, N., N. Boyer, P. Todoroff, M. Hajj, and A. Bégué. 2009. "Potential of SAR Sensors TerraSAR-X, ASAR/ENVISAT and PALSAR/ALOS for Monitoring Sugarcane Crops on Reunion Island." *Remote Sensing of Environment* 113 (8): 1724–1738.

Baghdadi, N., P. Todoroff, and M. Zribi. 2011. "Multitemporal Observations of Sugarcane by TerraSAR-X Sensor." *IEEE International Geoscience and Remote Sensing Symposium*, Vancouver, BC, July 24–29, 1401–1404.

Brisco, B., R. J. Brown, J. G. Gairns, and B. Snider. 1992. "Temporal Ground-Based Scatterometer Observations of Crops in Western Canada." *Canadian Journal of Remote Sensing* 18 (1): 14–22.

Formaggio, A. R., J. C. N. Epiphanio, and M. S. Simões. 2001. "Radarsat Backscattering from an Agricultural Scene." *Pesquisa Agropecuária Brasileira* 36 (5): 823–830.

Fortes, C., and J. A. M. Demattê. 2006. "Discrimination of Sugarcane Varieties Using Landsat 7 ETM+ Spectral Data." *International Journal of Remote Sensing* 27 (7): 1395–1412.

Haraguchi, M., Y. Akamatsu, T. Morita, C. Kobayashi, and M. Kawai. 2010. "Biofuel Field Mapping and Growth Monitoring Using Palsar Data." *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Science* XXXVIII, Part 8: 572–575.

Hoffmann, H. P., E. G. D. Santos, A. I. Bassinello, and M. A. S. Vieira. 2008. *Variedades RB de Cana-de-Açúcar*. Araras: Universidade Federal e São Carlos.

Igarashi, T. 2001. "Alos Mission Requirement and Sensor Specifications." *Advances in Space Research* 28 (1): 127–131.

Jiaguo, Q., W. Cuizhen, I. Yoshio, Z. Renduo, and G. Wei. 2004. "Synergy of Optical and Radar Remote Sensing in Agricultural Applications." In *Proceedings of the SPIE on Ecosystems' Dynamics, Agricultural Remote Sensing and Modeling, and Site-Specific Agriculture*, edited by W. Gao, and R. David. Vol. 5153, 153–158. Accessed May 13, 2013. http://spie.org/

Lin, H., J. Chen, Z. Pei, S. Zhang, and X. Hu. 2009. "Monitoring Sugarcane Growth Using ENVISAT ASAR Data." *IEEE Transactions on Geoscience and Remote Sensing* 47 (8): 2572–2580.

Mann, H. B., and D. R. Whitney. 1947. "On a Test of Whether One of Two Random Variables is Stochastically Larger than the Order." *The Annals of Mathematical Statistics* 18 (1): 50–60.

Martorano, L. G., L. R. Angelocci, C. A. Vettorazzi, and R. O. A. Valente. 1999. "Zoneamento Agroecológico para a Região de Ribeirão Preto Utilizando um Sistema de Informações Geográficas." *Scientia Agricola* 56 (3): 739–747.

McNairn, H., and B. Brisco. 2004. "The Application of C-Band Polarimetric SAR for Agriculture: A Review." *Canadian Journal of Remote Sensing* 30 (3): 525–542.

McNairn, H., K. Hochheim, and N. Rabe. 2004. "Applying Polarimetric Radar Imagery for Mapping the Productivity of Wheat Crops." *Canadian Journal of Remote Sensing* 30 (3): 517–524.

Moran, M. S., A. Vidal, D. Troufleau, Y. Inoue, and T. A. Mitchell. 1998. "Ku- and C-Band SAR for Discriminating Agricultural Crop and Soil Conditions." *IEEE Transactions on Geoscience and Remote Sensing* 36 (1): 265–272.

Oliveira, J. B., M. N. Camargo, M. Rossi, and B. Calderano Filho. 1999. *Mapa Pedológico do Estado de São Paulo – Legenda Expandida*. Campinas: Instituto Agronômico de Campinas.

Paloscia, S. 1998. "An Empirical Approach to Estimating Leaf Area Index from Multifrequency SAR Data." *International Journal of Remote Sensing* 19 (2): 359–364.

Pampaloni, P., G. Macelloni, S. Paloscia, and S. Sigismondi. 1997. "The Potential of C- and L-Band SAR in Assessing Vegetation Biomass: The ERS-1 and JERS-1 Experiments." *The 3rd ERS Symposium on Space at the Service of our Environment*, Florence, March 17–21, 3: 1729–1733.

Paradella, W. R., A. R. Santos, P. Veneziani, and E. S. P. Cunha. 2005. "Radares Imageadores nas Geosciências: Estado da Arte e Perspectivas." *Revista Brasileira de Cartografia* 57 (1): 56–62.

Paris, J. F. 1983. "Radar Backscattering Properties of Corn and Soybeans at Frequencies of 1.6, 4.75 and 13.3 GHz." *IEEE Transactions on Geoscience and Remote Sensing*, GE-21 (3): 392–400.

Prado, H. 2005. *Ambientes de Produção de Cana-de-Açúcar na Região Centro-Sul do Brasil. Encarte Técnico*. Informações Agronômicas, 110, June 2005. Accessed February 25, 2010. http://www.ipni.net/ppiweb/brazil.nsf/87cb8a98bf72572b8525693e0053ea70/7759ddc6878ca7eb83256d05004c6dd1/$FILE/Encarte110.pdf

Prado, H., M. G. A. Landell, R. Rossetto, M. P. Campana, L. Zimback, and M. A. Silva. 1998. "Relation between Chemical Subsurface Conditions of Subsoils and Sugarcane Yield." *The 16th World Soil Science Congress*, Montpellier, August 20–26, 1: 232.

RADARSAT-2. 2013. *Canada's Next Generation SAR Satellite*. Accessed May 03, 2013. http://gs.mdacorporation.com/SatelliteData/Radarsat2/Radarsat2.aspx

Rosenqvist, A., M. Shimada, N. Ito, and M. Watanabe. 2007. "Alos Palsar: A Pathfinder Mission for Global-Scale Monitoring of the Environment." *IEEE Transactions on Geoscience and Remote Sensing* 45 (11): 3307–3316.

Rudorff, B. F. T., D. A. Aguiar, W. F. Silva, L. M. Sugawara, M. Adami, and M. A. Moreira. 2010. "Studies on the Rapid Expansion of Sugarcane for Ethanol Production in São Paulo State (Brazil) using Landsat Data." *Remote Sensing* 2 (4): 1057–1076.

Shimada, M., O. Isoguchi, T. Tadono, and K. Isono. 2009. "Palsar Radiometric and Geometric Calibration." *IEEE Transactions on Geoscience and Remote Sensing* 47 (12): 3915–3932.

Silva, W. F., B. F. T. Rudorff, A. Formaggio, W. R. Paradella, and J. Mura. 2009. "Discrimination of Agricultural Crops in a Tropical Semi-Arid Region of Brazil based on L-Band Polarimetric Airborne SAR Data." *ISPRS Journal of Photogrammetry and Remote Sensing* 64 (5): 458–463.

Simões, M. S., J. V. Rocha, and R. A. C. Lamparelli. 2005. "Growth Indices and Productivity in Sugarcane." *Scientia Agricola* 62 (1): 23–30.

UNESP (Universidade Estadual Paulista Júlio de Mesquita Filho). Resenha Meteorológica do Período 1971–2000. Jaboticabal. Accessed January 20, 2011. http://jaguar.fcav.unesp.br/portal_agromet/int_conteudo_sem_img.php?conteudo=180

Wegmüller, U., M. Santoro, F. Mattia, A. Balenzano, G. Satalino, P. Marzahn, G. Fischer, R. Ludwig, and N. Floury. 2011. "Progress in the Understanding of Narrow Directional Microwave Scattering of Agricultural Fields." *Remote Sensing of Environment* 115 (10): 2423–2433.

Yun, S., G. Huadong, L. Hao, L. Junfei, and L. Xinqiao. 1995. "Effect of Polarization and Frequency using GlobeSAR Data Vegetation Discrimination." *Geocarto International* 10 (3): 71–78.