# DELINEATION OF PALM SWAMPS USING SEGMENTATION OF RADARSAT DATA AND SPATIAL KNOWLEDGE

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**ABSTRACT**

Among the alluvial communities of the *cerrado* (Brazilian savanna), palm swamps represents an important and fragile ecosystem that develop under very specific geomorphologic conditions associated with a river system and a mostly flat topography. In the cerrado, the term *veredas* describes palm swamps that are mainly associated with *Mauritia flexuosa*. Veredas are in fact vegetation complexes composed of a succession of vegetation forms that range from grassland to forest. Veredas are protected by law in Brazil but their extent and condition are mainly unknown. As a humid environment in a semiarid context and being associated with a very specific topographic and hydrographic context, veredas are easily detected on remotely sensed data but are also often mistaken for riparian forests when using optical data. Being very sensitive to humidity, synthetic aperture radar data from RADARSAT offers good potential for delineating veredas.
In this article, a methodology is described for the delineation of veredas using a segmentation approach limited to a buffer based on the hydrographic network. The segmentation technique is based on a “modified adaptive Markov random field” (MAMSEG) algorithm that solely uses the SAR backscattering data. Segmentation is performed exclusively within the buffer area and only segments connected to the hydrographic network are kept. Preliminary results suggest a correspondance of about 70% between the segments extracted and the actual localization of the veredas. Additionally, it appears that filtered RADARSAT data offers some potential for separating vegetation forms within the veredas ecosystem.

**RÉSUMÉ**

Parmi les communautés alluviales du *cerrado* (savane Brésilienne), les marais à palmiers représentent un écosystème important et fragile qui se développe dans des conditions géomorphologiques spécifiques associées à un système fluvial et une topographie presque plate. Dans le cerrado, ces marais sont désignés par le terme *veredas* auquel est associé *Mauritia flexuosa*. Les veredas sont en fait des complexes de végétation composés d’une succession de formations végétales allant des herbacés au formations forestières. Les veredas sont protégées par la loi au Brésil mais leur étendue et leur état sont mal connus. Étant des zones humides permanentes dans un environnement semi-aride et associées à un contexte topographique et hydrographique très spécifique, les veredas sont facilement détectées par télédétection mais sont souvent confondues avec d’autre formations riveraines sur les images optiques. Par leur sensibilité à l’humidité, les données radar d’ouverture synthétique de RADARSAT offrent un bon potentiel pour la délimitation des veredas.
Le présent article décrit une méthode pour délimiter les veredas à partir d’une approche de segmentation restreinte à une zone tampon basée sur le réseau hydrographique. La technique de segmentation est basée sur une approche “adaptive modifiée des champs de Markov” (MAMSEG) qui n’utilise que la rétrodiffusion radar. La segmentation n’est effectuée qu’à l’intérieur de la zone tampon et seulement les segments contigus au réseau hydrographique sont gardés. Les résultats préliminaires suggèrent une correspondence de 70% entre les segments extraits et la localization mesurée des veredas. De plus, les données RADARSAT filtrées offrent un certain potentiel pour séparer les différentes formations végétales qui composent les systèmes de veredas.

## 1. INTRODUCTION

Palm swamps are an important ecosystem found in the Brazilian savanna bioma. Found at the intersection of superficial and underground water flow, they act as a regulation mechanism for water availability between the wet and dry seasons. They also act as an essential water storage for the wildlife and local populations. In Brazil, palm swamps are threatened by the rapid conversion of savanna into agricultural land (especially eucalyptus and soy monoculture) and pasture for livestock. Neither the extent or degree of conservation of palm swamps are known and a recognized methodology for their delineation and characterization still evades the scientific community.

Airborne and orbital Synthetic Aperture Radar (SAR) has proven its utility in a wide variety of environmental applications (F. M. Henderson and A. J. Lewis (eds.), 1998). Land use/land cover delineation, estimation of bio-physical parameters for forest structure and the study of wetlands are amongst these applications. In the wetland environment, SAR imagery have been successfully used in applications where optical imagery is of little help like determining soil humidity, detecting the hydrographic network under the forest canopy or delineating flooded forests. In climates ruled by distinct wet and dry seasons like Brazil, the fact that SAR sensors are almost unaffected by clouds and light rain gives it a great advantage over optical instruments (Bonn and Rochon, 1992, p. 218). For that reason, these regions are almost never studied with optical sensors during the rainy season; an important limitation for remote sensing in the tropics.

Although SAR data proves valuable for the delineation of wetlands and flooded areas, traditional information extraction methods like threshold and classification (*e.g.* maximum likelihood, minimum distance) are usually useless with radar data. The fact that only one band is acquired (except in multi-polarimetric mode) and the presence of speckle noise are the two main contributors to this situation. In that context, image segmentation using Markov random fields (MRF) has produced promising results in a variety of applications like image segmentation and restoration (Tso and Mather, 2001). In particular Deng and Clausi (2005) have proposed an original implementation of MRF-based segmentation (Modified Adaptive MRF Segmentation or MAMSEG) which was successfully applied to sea ice segmentation and labelling (Maillard and Clausi, 2005). The same algorithm has been chosen here in an effort to assess its usefulness for the current application.

The objective of this article consists in testing a segmentation approach (MAMSEG) for the extraction of palm swamps (*veredas*) from RADARSAT-1 data in the regional context of the Brazilian savanna. Since palm swamps are systematically found along streams (that may or may not have a defined river bed), it was decided to use this spatial knowledge to guide and restrict the segmentation using cartographic modelling.

### 1.1. SAR Data in Humid Environments

SAR data started to be more consistently used for the study of ecological processes in the 80´s for the determination of parameters that could not be extracted directly from optical instruments such as soil humidity, bio-physical characterization of vegetation, some hydrological features and micro-relief (Parmuchi et al., 2002). Understanding these processes from SAR data is not trivial since the interaction between microwave incident radiation and the Earth´s surface is complex and needs to be better understood (Horrit et al., 2003). It is known that the radar return signal is influenced by the target properties (dielectric constant, surface texture or roughness, topography), by the SAR parameters of frequency (band K-P) and polarization (HH, VV, HV, VH) and by the incident angle between the instrument and the surface (Kasischke et al., 1997). Another advantage of SAR over optical data is that the former has the capacity (depending on the band chosen) for its signal to penetrate the vegetation canopy and return information relative to branches, trunk and ground (Kasischke et al., 1997). Depending on the frequency used and the nature of the surface, flooded areas will display a characteristic behavior. Calm waters generally act as a quase-specular surface reflecting all incoming signal with an angle equal to the incident angle but in the opposed direction. This effect will cause open water areas to appear black and grassland or forested areas to cause the signal to bounce back at the antenna and create a strong return with an almost white appearance on the SAR image (Leckie and Ranson, 1998; Kandus et al., 2001; Parmuchi et al., 2002).

A study from (Kasischke et al., 1997) using multi-frequency and multi-polarization SAR data has shown that the “double bounce” phenomenon in forested areas is stronger for longer wavelengths (L and P bands) because in shorter wavelength (K, X and C bands) the signal is significantly attenuated by the canopy except during the leaf-off period or when the canopy is open or discontinuous (being the case of the Brazilian savanna). In grassland, this phenomenon is still present for the higher frequency bands (K, X, C) that respond to small leaves and branches. In another study in the Peace-Athabasca Delta (Canada), Adam et al. (1998) have showed evidence that co-polarized (HH) C-band radar data could be efficiently used to delineate flood extents even below the forest canopy.

The angle of incidence is also an important factor for the determination of flooded areas. Most orbital radars can vary their angle of incidence between 20$^o$ e 50$^o$ with the exception of RADARSAT that can operate in the interval 10$^o$ to 60$^o$ (RADARSAT Internacional, 2000). According to Paloscia (2002), it was observed that the interfering effect of the forest canopy can be reduced by using a small incidence angle. Larger angles of incidence are useful for the determination of the vegetation structure but are not recommended for the determination of flood extend.

### 1.2. Study Area

The study area is situated along the course of the *Peruaçu* river in Northern Minas Gerais / Brazil, in an area called *Chapadão das Gerais*. The area was chosen for being one of the rare well preserved region of the Brazilian savanna having ideal environmental conditions for the research (being a protected area) and having some of the longest palm swamp area of the country (Figura 1). The *Peruaçu* river is an affluent of the *São Francisco* river, the third largest watershed of Brazil. The region´s bedrock is composed of a layer of sandstone (usually highly weathered) over carbonates of the superior Proterozoic. The topography is very flat and the differences between the more elevated savanna and the lower palm swamps is hardly perceptible. The climate is semiarid with an average temperature of over 25$^o$C. Precipitation averages 124mm per month between October and April and less than 2mm between May and September (Nimer and Brandão, 1989).

The whole study area is covered by savanna in its various forms to which are associated palm swamps. In the region, these variations of the savanna are associated with the availability of water in the soil and so is the presence of palm swamps (Gomes and Maillard, 2003). Generally speaking, the closer the water streams, the more water is available and the more developed the vegetation to culminate into forested savannas (*cerradão*). The flat terrain causes the river flow to be rather slow which, combined with bedrock properties that facilitate the water table to surface, make up the required conditions for palm swamps to develop. Palm swamps known in Brazil as *veredas* are a common hydrophilous vegetation form in the gentle rolling valleys of central Brazil (Achá-Panoso, 1978) and are often referred to in the Brazilian literature. Even then, no consensus has been reached over their complete definition. Their physiognomy includes a gradation of vegetation forms usually starting with a seasonal gramineous field followed by a permanently saturated swamp. In the central part of that swamp there are usually a band of varying width of palms commonly called *buriti* (*Mauritia flexuosa*) that are sometimes accompanied by a shrub layer or even a sciero-

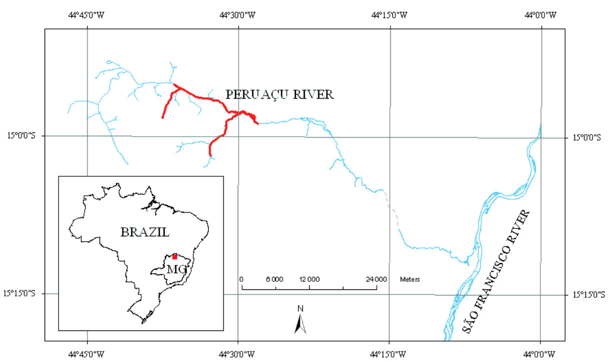
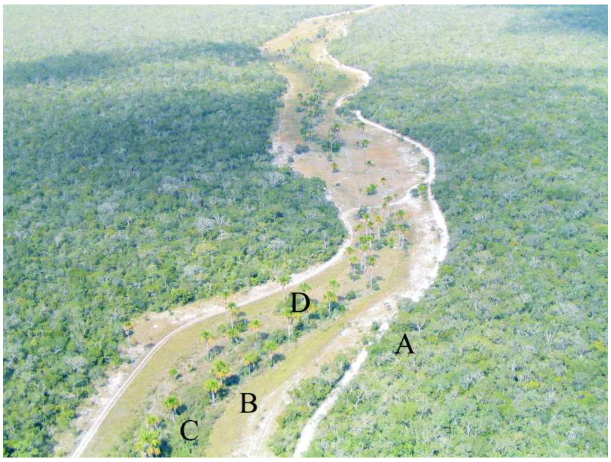
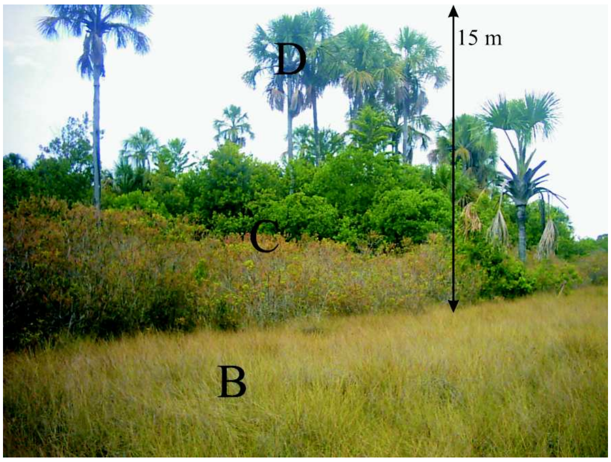



Figure 1: Location of the study area.




(a)




(b)

Figure 2: Photographs illustrating the different physiognomies of palm swamps (a) as seen from the air and (b) from the ground: A - Savanna, B - Grassland, C - Shrub/Scierophylous stage, D - *Buriti* palms.

phylous riparian forest. Figure 2 shows a typical example of the various vegetation stages of a palm swamp in savanna setting.

Palm swamps constitute an ecosystem of its own that requires certain geologic, geomorphologic and climate conditions to develop. Four distinct subunits can be identified: 1) the evolutionary zone, 2) the dry zone, 3) the saturated zone and 4) the river channel (Melo, 1992). The evolutionary zone is represented by the tabular areas that skirt the swamp and is characterized by savanna vegetation on a sandy soil over a sandstone bedrock. The dry zone corresponds to the mildly sloping terrain between the evolutionary zone and the saturated zone and is usually covered by grassland. The saturated zone covers the flat bottom of the *vereda* filled with a layer of sandy-clay soil of 40–80 cm capped with a layer of about 20 cm of turf. Finally, the channel is a zone of slowly flowing open water over peat soil. As mentioned above, palm swamps bear a great social and ecological importance and, as such are protected by law.

## 2. MATERIAL AND METHODS

### 2.1. Image Acquisition and Pre-processing

Four RADARSAT-1 images were acquired for the present study from a "Data for Research Use" (DRU) project promoted by the Canadian Space Agency (CSA). RADARSAT-1 is an orbital SAR operating in the C band with a 5.3 GHz frequency (wavelength $\lambda = 5.6cm$). Its sensor is horizontally co-polarized (HH) with a varying incidence angle (10$^o$ in Low Incidence Beam Mode and 60$^o$ in High Incidence Beam Mode) and can produce images with a spatial resolution between 8m in Fine Mode and 100m in SCANSAR Mode. The images were acquired in the "standard beam" mode for two distinct periods corresponding to the two main phenological seasons: Abril or the end of the wet season when the soil is saturated and September or the end of the dry season when the hydrological balance is at its lowest. For each period, two images of different incidence angles were acquired: S2 (24$^o$ to 31$^o$ for the near and far range respectively) and S6 (41$^o$ to 46$^o$). The images have a spatial resolution of 12.5m and a radiometric depth of 16 bits. SAR images with these varying characteristics were ordered in an effort to assess the best period/incident angle for characterizing the structure of savanna vegetation including palm swamps. It was expected that S6 scenes would be more affected by volume scattering and vegetation structure consequently (Töyrä et al., 2001; Townsend, 2002) and that the S2 scenes would respond more to direct scattering and soil humidity.

Visual analysis of the SAR images reveals that the September images (dry season) show better contrast between the various elements of the scene (Figure 4). On both dates, the palm swamps have relatively high digital numbers whereas the savanna appears relatively darker. The S2 images tend to enhance better the contrast between savanna and palm swamps. As for the season, the end of the wet season (April) shows a better contrast than the dry season images. It can be deduced that, visually at least, smaller angle of incidence and saturated soils are better for delineating *veredas*.

All four images were corrected geometrically using both image-to-image (based on a geo-referenced Landsat ETM+ panchromatic band with a ground resolution of 15m) and *in situ* ground control points collected with a hand-held GPS. Since the relief is mostly flat, displacement effects caused by the incidence angle were almost negligible and all four images had mean square errors below 20m. The data was not calibrated since this was not necessary for the present study and could have resulted in decreasing the contrast between the targets. Speckle noise was not filtered because it was expected that the MRF segmentation algorithm would not be affected by such noise (Deng and Clausi, 2005).

### 2.2. Field Work

Field work was realized in September 2005 towards the end of the dry season. Using a hand-held GPS, eighteen transects were

Table 1: Imagens RADARSAT-1 utilizadas.

| Acquisition date | Mode | AI | Resolution |
|---|---|---|---|
| 02/04/2004 | S2 | 24-31 | 12,5m |
| 03/04/2004 | S6 | 41-46 | 12,5m |
| 17/09/2004 | S2 | 24-31 | 12,5m |
| 18/09/2004 | S6 | 41-46 | 12,5m |

measured and characterized across palm swamps of the Peruaçu river and some of its tributaries. For each transect, all the different physiognomies of the palm swamp vegetation were described and their extent along the transect measured. Normal and hemispherical canopy photographs were taken to accompany the description of every transect (Figure 3). Seven of these transects were used in the present study which corresponds to a subsection of the whole area inscribed in a relatively small diameter ($\pm 16km$) where the palm swamps are relatively continuous. For this phase of the research[1], the different physiognomies were merged into *veredas* or *non-veredas* to determine the capacity of the segmentation algorithm and RADARSAT-1 images for delineating palm swamps. Transects were positioned arbitrarily with no other criterion than being separated by a minimum distance of one kilometer. It should be noted that, even though field work was conducted in the dry season, most palm swamps are partially flooded and difficult (if not dangerous) to access by foot and this bias was unavoidable in this first phase. The transects were digitized and color-coded according to the physiognomy of the vegetation and overlayed on the segmented images (Figure 3d).

### 2.3. Data Processing

Processing involved both cartographic modelling and image processing. The approach consists in using spatial knowledge to “limit” the search to areas having a strong probability of belonging to palm swamps. To do so, the hydrographic network was digitized and overlayed on the image (Figure 3a) and used to build a buffer of one kilometer (knowing the palm swamp width is well below that value) based on the fact that palm swamps are always linked to the low relief and follow slowly flowing streams. The buffer was then used to mask parts of the image that fell outside of it (Figure 3b). The SAR image and the mask are then fed to the segmentation algorithm which is instructed to find only two classes (or segments since the results have not yet been labelled; Figure 3c). The segmentation results are then cleaned using a majority filter to remove very small clusters and all the segments not contiguous to the hydrographic network are eliminated to ensure other wetlands (for example surrounding small lakes that are present in the region) are not included in the palm swamp class. Finally the results are validated by overlaying field transects (in the form of vectors) on the segmented image (Figure 3d).

The segmentation was performed using MAMSEG, a MatLab-based algorithm developed by Deng and Clausi (2005) based on a modified adaptive implementation of MRF theory. The advantage of MRF models lies in their ability to inherently describe spatial context: the local spatial interaction among neighboring pixels. This is most appropriate since neighboring pixels are generally not statistically independent but spatially correlated. The Markov assumption states that the conditional probability of a pixel value given its neighborhood is equal to the conditional probability of that pixel given the rest of the image. This makes it possible to consider each pixel with its local neighborhood as an independent process making it more easily modelled in mathematical terms (Tso and Mather, 2001). Considering the present context, MRF models have already shown to provide an appropriate representation of noisy SAR images given their variance (due to speckle) and texture (Krishnamachari and Chellappa, 1997; Liu et al., 2004; Dong et al., 2004).

MAMSEG can process more than one feature. For instance, Deng and Clausi (2005) and Maillard and Clausi (2005) used a

[1] A future phase will combine the results of the first phase with optical data in an effort to characterize each physiognomy using ASTER optical data.

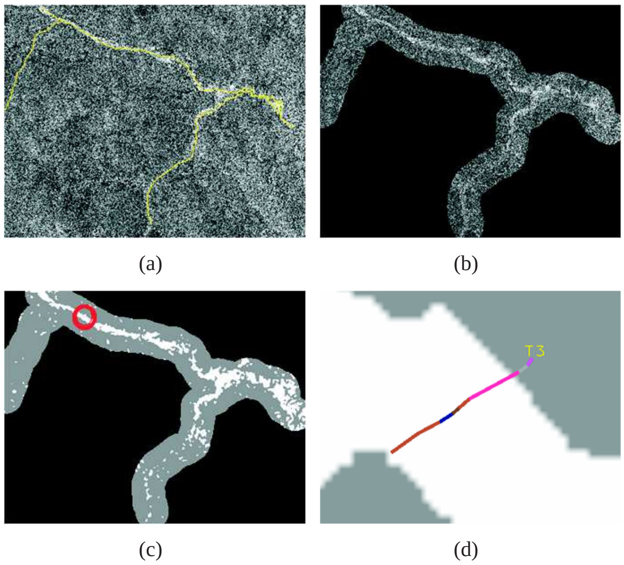


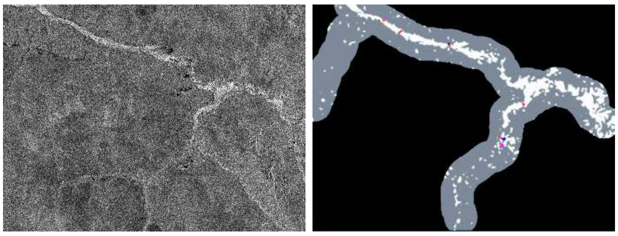

Figure 3: Illustration of the four conceptual steps of the approach: (a) the hydrographic network overlaying the SAR image, (b) masking the image with the hydrographic network buffer, (c) segmenting the masked image using only two classes, and (d) validating the result using field data in the form of transects (corresponding to the circled area in c).

combination of raw SAR data and texture features but in this first phase, only the raw SAR data was used. Two parameters have to be specified for the segmentation to take place: 1) the number of classes and 2) the number of iterations. The number of classes was set to two for a binary result of palm swamp/non palm swamp. The number of iteration was varied between 50 and 120 by increments of 10. It was found that the results became very stable after about 70 iterations and so all the results presented in the following section used 80 iterations.

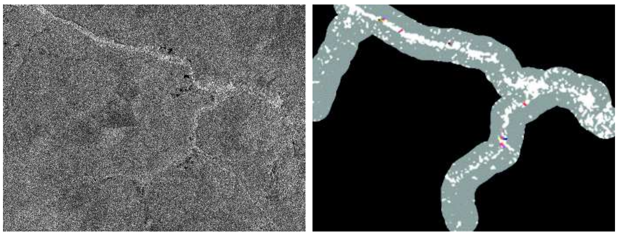
## 3. RESULTS AND DISCUSSION

The segmentation results are presented in Figure 4 and in Table 2. The first striking observation is that results from April scenes have a much better visual correspondence with the spatial behavior expected: a central strip of palm swamp (white color) bordered by savanna (grey color). This was expected since, as mentioned in Section 2.1, the wet season scenes (April) show a better visual contrast between savanna and palm swamps (Figure 4). This can be explained by the fact that many swamp areas are flooded during the wet season and this causes a “double bouncing” phenomenon between the water surface and the vegetation. This also corroborates finding of other studies involving wetlands (Leckie and Ranson, 1998; Kandus et al., 2001; Parmuchi et al., 2002). In non-flooded areas, it is probably the combination of coarse texture from the dense vegetation and saturated soils (high dielectric value) that gives palm swamps their bright appearance.

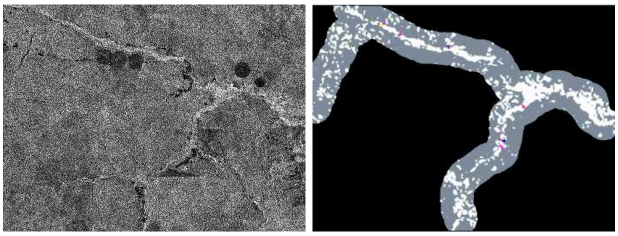
During the dry season, the soil is much less saturated and there are almost no flooded parts in the swamps, therefore double bouncing is absent and only direct backscattering from the humid soil is captured by the S2 (small incidence angle) scene. The fact that the palm swamps appear larger in the September scene is inherent to the MAMSEG segmentation algorithm that does not



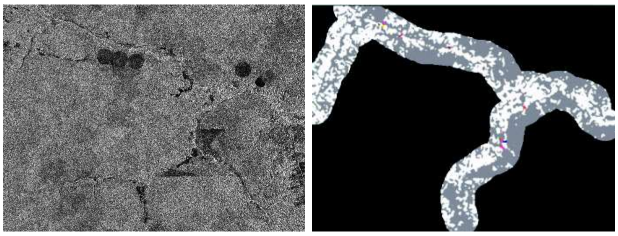
(a) April S2



(b) April S6



(c) September S2



(d) September S6

Figure 4: SAR images (left) and segmentation results (right) obtained with the MAMSEG algorithm for the two periods and the two incidence angles using 80 iterations.

manage to stabilize and tends to converge towards a single class. This aspect is somewhat problematic in MRF segmentation and requires more attention in future work.

It can also be observed that the East-West palm swamps are wider and almost continuous whereas both North-South legs are quite fainted or discontinuous. This is consistent with what was observed in the field and can be corroborated by a CBERS (China-Brazil Earth Resource Satellite) image of the area (Figure 5) where it can be observed that the Western North-South leg is very thin and probably degraded and the Eastern one discontinuous in some parts.

Table 2 shows the percentage of each transect that finds a correspondence on the segmented images. Other transects were measured but fall outside the area of interest of the present study. The total length of the transects are also shown for reference purposes. Seven transects were used for validation for a total length of 1887 m or about 151 pixels. The validation results confirm what was observed on the segmented images. The April S6 scene yielded an average score of $\approx 70\%$ but the other April image

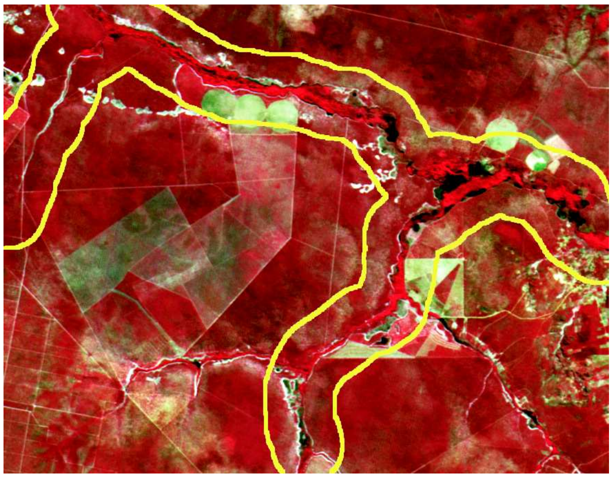


Figure 5: CBERS (China-Brazil Earth Resource Satellite) optical image of the area of interest. Note the distinct red aspect of East-West palm swamps and the discontinuities in the North-South legs (image ©Instituto Nacional de Pesquisa Espacial - INPE, Brazil, http://www.inpe.br.)

(S2) gave the worse score of $< 50\%$. The two September scenes produced similar results of $62.7\%$–$64.5\%$. It should be noted that these results correspond to the producer's accuracy ($100\% -$ omission errors) since only the pixels left out of the palm swamp were considered. In that respect, the visual results bear a significant importance. Future field work will register transects comprising both palm swamps and other classes (especially savanna).

Table 2: Proportion (in percentage) of each transect that effectively corresponds to palm swamps for all four SAR images. The average score of each transect and each image is also shown.

| Transect | Length (m) | April S2 | April S6 | September S2 | September S6 | Mean |
|---|---|---|---|---|---|---|
| T1 | | 19.39 | 82.74 | 100.0 | 100.0 | 75.53 |
| T2 | | 72.52 | 19.91 | 57.21 | 86.51 | 59.04 |
| T3 | | 80.12 | 94.10 | 36.55 | 36.67 | 61.86 |
| T4 | | 0.00 | 100.0 | 35.80 | 46.51 | 45.58 |
| T5 | | 96.33 | 78.81 | 91.69 | 96.33 | 90.79 |
| T6 | | 38.53 | 54.02 | 50.48 | 40.14 | 45.79 |
| T7 | | 23.17 | 62.30 | 80.03 | 32.48 | 49.50 |
| Mean | | 47.15 | 70.27 | 64.54 | 62.66 | |

## 4. CONCLUSION

The research presented in this article is still in its preliminary phase but encouraging results were obtained. Palm swamps are important ecosystems but are still hilly defined. It appears that RADARSAT-1 images are well suited for the detection of palm swamps and that the MAMSEG algorithm can be appropriate for their fast delineation. The main findings are outlined below.

- Palm swamps are detected from two main phenomenon: double bouncing and high water content in the soil.
- Dense canopies tend to decrease the detection capacity of palm swamps.
- Wet season SAR image offer better conditions for delineating palm swamps.

- Larger incidence angles are better during the wet season and possibly worse during the dry season.
- SAR images have a good potential for separating palm swamps from riparian forest.
- Segmentation of SAR images using MRF principle is an appropriate method for delineating palm swamps as long as proper parameters (band and incidence angle) and season are chosen.

Future work will focus on acquiring more ground data (both more transects and more measurements such as leaf area index and soil moisture) and a more rigid definition of palm swamps. The incorporation of more feature (*e.g.* texture, optical data, digital elevation model) is also being considered to take full advantage of the segmentation algorithm.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