Synthetic Aperture Radar for Recognition of Coastal Features in the Wet Tropics: Applications in the Brazilian Amazon Coast

Radar de Abertura Sintética para Reconhecimento de Feições Costeiras nos Trópicos Úmidos: Aplicação na Costa Amazônica Brasileira

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Abstract: Synthetic Aperture Radar (SAR) data with distinct operational configurations (frequency, viewing terrain geometry, resolution, etc) has been acquired in the Amazonian Region in the last ten years. As the Amazon coast is subject to rain, cloud, haze and smoke, SAR imageries are a powerful tool to provide coastal geology information due to the enhancement of the terrain caused by the side-view geometry and all-weather sensing capability. In this paper, we discuss the effect of digital image processing and interpretation of SAR images for recognizing coastal features in the wet tropics from the mangrove environment, paleo-alluvial and lacustrine system and mudcapes along the northern Brazilian coast. The application of microwave remote sensing data in the tropics has shown that an effective applicability of the SAR technology only will be expanded with the understanding of radar fundamentals, digital image processing, good field information and the knowledge about the application involved.

Key Words: RADARSAT-1; JERS-1; Coastal wetlands; Amazon.

Resumo: Radares de abertura sintética (SAR) com diferentes configurações operacionais (freqüência, geometria de visada, resolução etc) têm adquirido dados na região amazônica nos últimos dez anos. Como a região costeira amazônica é envolvida por chuvas, nuvens, neblina e fumaça, imageamentos com SAR representam uma poderosa ferramenta para geração de informações sobre geologia costeira, devido ao realce do terreno causado pela geometria de visada-lateral e pela capacidade de imageamento em condições atmosféricas adversas. Neste artigo, discutiremos o efeito do processamento digital de imagens e da interpretação de imagens SAR no reconhecimento de feições costeiras nos trópicos úmidos a partir de ambientes de manguezal, de sistemas lacustrinos e paleo-aluviais e de cabos lamosos ao longo da costa norte brasileira. A aplicação de dados de sensoriamento remoto nas microondas tem mostrado que uma aplicabilidade efetiva da tecnologia SAR somente se expandirá com o entendimento da fundamentação de radar, do processamento digital de imagens, de boas informações de campo e do conhecimento sobre as aplicações envolvidas.

Palavras-Chave: RADARSAT-1; JERS-1; Zonas úmidas costeiras; Amazônia.

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INTRODUCTION

Distinct from optical sensors which extract target's information related to chemical composition and physical structure of the material from the reflected sunlight, backscattered microwave energy from the Earth's surface measured by a Synthetic Aperture Radar (SAR) provides information about the terrain's physical (macro-topography, slope, roughness) and electrical properties (mainly controlled by the moisture content). The generation of image products from SAR data has required intensive machine processing since the data started being recorded in digital format rather than as a hologram (Lewis *et al.*, 1998). Both the system engineer and the geoscientist require the production of high quality dataset, be it in analog or digital format. Whereas for the system engineer this product may represent the final data, for the geoscientist it normally represents the input data for further interpretation. Geoscientist needs to know about the sensor's (wavelength, polarization and viewing geometry) and terrain's parameters (roughness, complex dielectric constant, shape, orientation) to extract consistent and valid information from the SAR data. Therefore, the quality of SAR interpretation increases with the geoscientist's understanding of radar fundamentals, the study site and the discipline vs. application involved (Lewis *et al.*, 1998).

Due to the adverse atmospheric conditions for acquisition of remote sensing data based on optical data, orbital SAR imageries (ERS-1, ERS-2, JERS-1, RADARSAT) have played a fundamental role as a powerful tool to map and monitor the wet tropical coastal environments (Rudant *et al.*, 1996; Singhroy, 1996; Barbosa *et al.*, 1999; Johannessen, 2000; Souza Filho, 2000; Costa *et al.*, 2002; Souza Filho; Paradella, 2002). Hence, the objective of this paper is to present results which emphasize the importance of SAR data for geomorphological coastal features study in the northern coast of Brazil.

STUDY SITES

Four areas were selected along the northern Brazilian coast The study sites were chosen based on theirs distinct terrain characteristics represented by a mangrove coast, paleo-alluvial setting, lacustrine system and mudcapes (Figure 1).

The mangrove coast occurs along the part of the Pará-Maranhão Coast and represents one of the largest mangrove ecosystems of the world with almost 8,900 km^2 (Kjerfve *et al.*, 2002). The selected area is represented by the Bragança coastal plain along the northeast of the State of Pará. This setting is characterized by low coastal wetlands with a 25 km width, subject to a macrotidal regime with a hot and humid equatorial climate, with an annual precipitation averaging 2,500 mm. Along the coastal plain the majors landforms observed are mangroves, salt marshes, tidal sandflats, chenier sandy ridges, coastal dunes, barrier-beach ridges and ebb-tidal deltas (Souza Filho; El-Robrini, 2000).

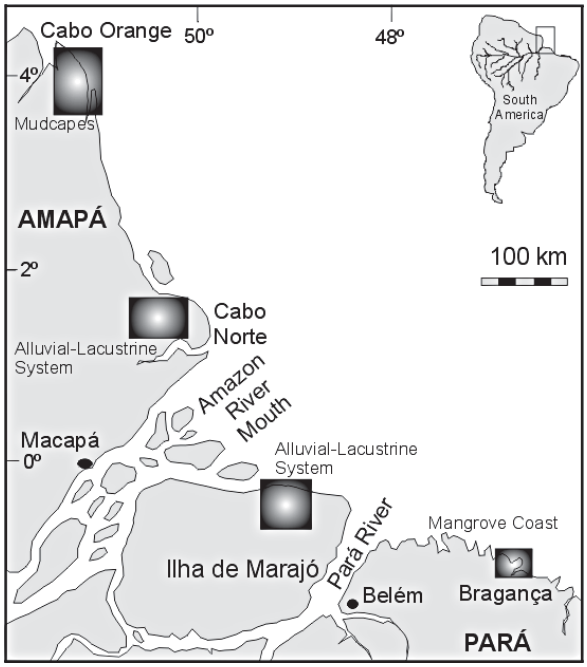

Figure 1. Location map of the study sites in the northern Brazilian coast.

The paleo-alluvial and lacustrine setting occurs in the eastern Marajó Island and in the Cabo Norte along the Amapá coast that represents one of the largest coastal alluvial-lacustrine environment of Brazil. This system presents a low fresh wetlands with altitudes less than 5 m and it occurs in the boundary of the Barreiras Group (Neogene deposits) with the coastal plain sediments. This setting is characterized by a hot and humid equatorial climate, with an annual precipitation averaging 3,000 mm. Along the alluvial plain different geomorphologic features are observed, such as lakes, paleo-channels, old levees, and mangroves and sandy beach ridges near the shoreline (Lima *et al.*, 1996), while the lacustrine system is connected by creeks and presents shallow waters with depths no more than 3.5 m (Costa, 1997).

The mudcapes occur along the Cassiporé and Orange capes in the northern Amapá coastal region. They are composed of muddy strata that, with continued accretion of a clinoform extension and colonization by mangroves at the cape tip, deflects the river mouth further downdrift (Allinson *et al.*, 1995). The area presents a low relief coastal plain (less than 10 m) of Holocene muddy sediments with up to 120 km wide. This wetland zone presents a hot and humid equatorial climate, with an annual precipitation averaging 3,000 mm. It is seasonally flooded and is characterized by lowland rainforest vegetation in well drained areas and grassland or marsh, punctuated by small lakes, elsewhere (Plaziat *et al.*, 1994).

DATA SET AND DIGITAL IMAGE PROCESSING

A data collection from distinct sources was used in this study. The RADARSAT-1 image (C-HH band, Fine Bean Mode 1, descending orbit) was acquired in 1998, under the Globesar-2 Program. The SAR JERS-1 (L-HH band) was acquired in 1995, under the NASDA Global Rain Forest Mapping Project South America (Rosenqvist, 1996). Details of the SAR remotely sensed data available for the investigation are presented in Table 1.

The principal image analysis system (IAS) used was PCI´s suite of remote sensing software, version 6.3 (PCI1999). Speckle suppression filtering for the Fine Mode image was applied as radiometric correction. The initial processing steps for the RADARSAT data included the scaling of the image from 16 to 8 bits. Afterward, a 3 x 3 adaptive enhanced-Frost filter was applied to reduce speckle effects (Lopes *et al.*, 1990) during the ortho-rectification process. Due to the fact that the study area presents an almost flat relief, it was considered unnecessary to utilize a digital elevation model during the ortho-rectification process to correct terrain distortions, which is a major factor in radar geometric correction due to off-nadir viewing (Toutin, 1995). Thus, the ortho-rectification geometric correction was applied with plain terrain model along the coastal plain. The image was registered to UTM projection based on twenty-five ground control points acquired during the field campaigns, with e-Trex Garmin GPS (accuracy = 7m). Based on the statistics of the ortho-rectification for the RADARSAT data, it was

Table 1. Characteristics of the remotely-sensed data.

Platform	Sensor	Acquisition Date	Incident angle	Spatial Resolution (m)	Swath (km)	Tide condition
RADARSAT-1	Fine 1	September, 1998	37-40°	9,1 x 8,4	50	High tide
JERS-1	SAR	Sep/Dec 1995	35°	93 x 93	Mosaic	*

*Scenes acquired in different tide conditions.

obtained a RMS accuracy around 12,24 meters. The RADARSAT-1 Fine image was further linearly stretched in order to enhance image attributes related to the coastal features. Finally, the SAR JERS-1 images were processed by NASA's Alaska SAR Facility, Jet Propulsion Laboratory and mosaicked by NASDA (NASDA/MITI, 1996), with a final pixel size of about 100 meters.

SAR FOR COASTAL STUDIES

Mangrove coast

Six prominent geological coastal features in the Bragança coastal plain were examined in details using the RADARSAT-1 Fine Bean Mode F1 scene. The image (Figure 2) was analyzed and evaluated aiming at the visual identification of coastal environment features and shallow water morphology. The image interpretation has indicated that intertidal mangroves (trees ~ 20 m height) show microwave responses mainly controlled by volumetric scattering and double-bounce mechanism. This is responsible for a very rough texture and light-gray tone allowing the discrimination of this system (Figure 2a). The supratidal mangrove presents a similar behavior, however related trees are smaller (~ 4m) and spaced, and reducing double-bounce effects. Hence, the roughness related to this target is finer and dark-grayish (Figure 2b).

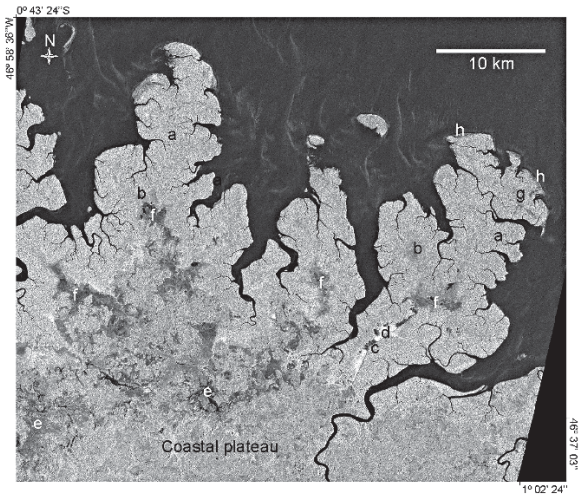

Figure 2. RADARSAT Fine Bean Mode (F1) from Bragança Coastal Plain. The letters are discussed in the text.

The inner marsh, completely flooded in the rainy season, presents a specular scattering behavior when the microwave radiation reaches the water surface, thus, appearing in a very dark tone in the image (Figure 2c). However, in the grass-covered inner marsh, the radiation interaction produces a slightly rougher surface with lighter gray tones (Figure 2d). The outer marsh shows a similar scattering mechanism as the inner one, but its geometry and spatial distribution are typical (Figure 2e).

The chenier sand ridges present a smooth surface and dark tones (Figure 2f). These characteristics appear to be controlled by the presence of dry sandy sediments of old dunes, which is responsible for absorption of the microwave radiation. This unit is bounded by an intertidal mangrove that presents light gray tone, which favors its discrimination.

Coastal dunes in RADARSAT-1 present a smooth and very dark surface (Figure 2g) due to specular scattering of microwave radiation by overlying water, which does not allow acceptable landform discrimination

From SAR image interpretation, shallow water morphology visible through the radar signature of ocean surface current changes and corresponding modulations of the shorter gravity-capillary waves (Johannessen, 2000). These SAR characteristics are responsible for wave front mapping in the surf zone and tidal current interactions with bottom features to locate and orient submerse sandy banks (Figure 2h). The spatial resolution of the RADARSAT Fine Beam Mode image allowed this investigation.

Paleo-alluvial and lacustrine settings

The occurrence of paleo-channels and lakes along the northern Brazilian coast was examined in details from the SAR JERS-1 images related to the Ilha de Marajó and Cabo Norte, respectively (Figure 3a,b).

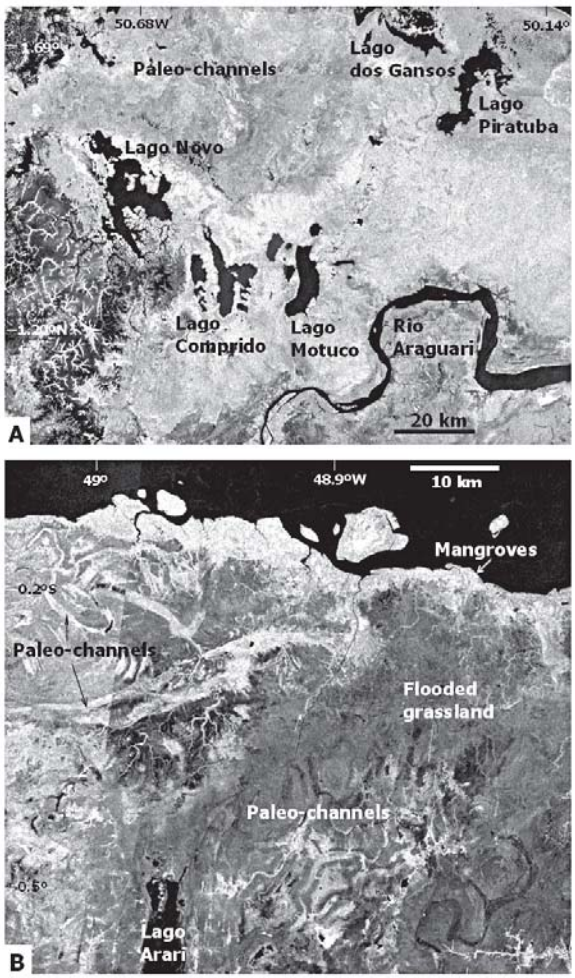

Figure 3. Paleo-channel and lacustrine setting in the Ilha de Marajó-Pará (a) and Cabo Norte-Amapá (b) from JERS-1 image.

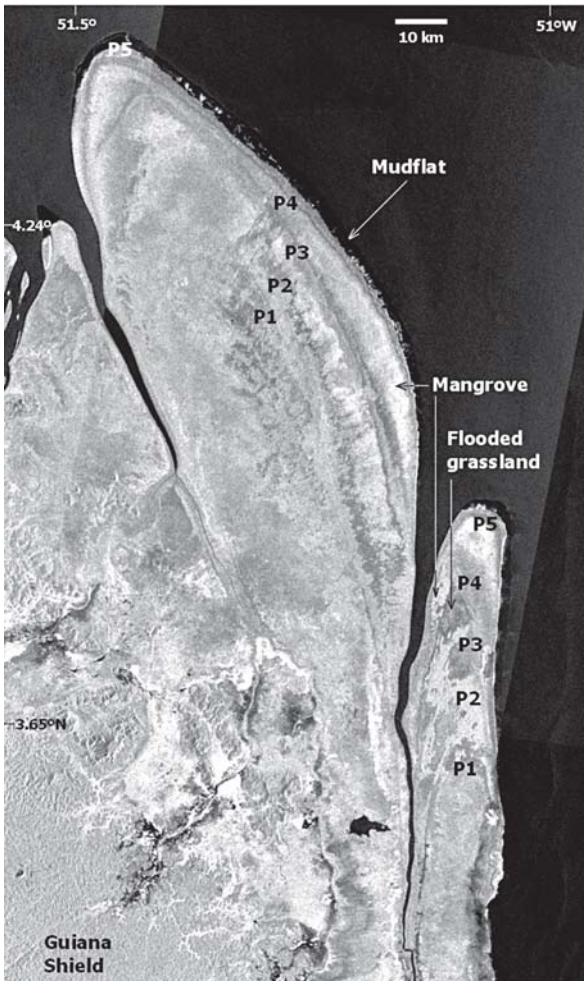

Figure 4. Cassiporé and Orange mudcapes along the Amapá coast from JERS-1 image.

According to Silveira (1998), the coastal lakes in the northern Brazil are formed in response to morphological changes of the coastal plain. From the interpretation of the L-band of the JERS-1, the surface of the lakes has presented a specular scattering behavior when the microwave radiation reaches the water table on the surface. As a consequence, these targets appear as very dark tone in the image (Figure 3a).

Paleo-channels have been extensively mapped along the northern Brazilian coastal plain (Bemerguy, 1981; Vital, 1988; Lima *et al.*, 1996; Silveira, 1998). Paleo-channels are covered by alluvial forest in contrast to theirs adjacent boundary covered by grasses of the low wetland flooded areas. Hence, the interpretation of the SAR JERS-1 image for the Ilha de Marajó area has allowed to get a good discrimination of the paleo-drainage. In this orbital SAR data the paleo-channels are expressed as light-gray tones due to volumetric scattering and double-bounce mechanisms, while the herbaceous flat (Campos do Marajó) is related to dark tones acting as a smooth surface in response to the L-band interaction with the target (Figure 3b). In the Lake

Region of Amapá coast, the paleo-channels are covered by grass and theirs boundary are vegetated by alluvial forest in opposition to alluvial setting observed in the Ilha de Marajó (Figure 3a).

Mudcapes

From the SAR JERS-1 image, it was possible to characterize the mudcapes due to their particular morphologic features linked to evolutionary stages and their coastal sedimentary environments. The morphologic features are related to accretionary lines, such as straight lines along the river; and arc lines in front of the cape (Figure 4). According to Silveira (1998) and Allinson *et al.* (2000), each accretionary line represents a stage into the evolution of the mudcapes, showing a progradational process of the Amapá muddy coast.

Along the mudcapes, mangrove system presents a light gray tones in response to volumetric scattering and double-bounce mechanism, while flooded grassland with rough surface occurs in gray tones and mudflat with smooth surface presents dark tones.

CONCLUDING REMARKS

Distinct SAR systems with different configurations have provided high quality data for coastal features identification in wet tropical environments where atmospheric conditions are adverse for the use of optical remote sensing data. However, the effective applicability of the SAR technology depends on the understanding of radar fundamentals, digital image processing, field investigations and the knowledge about the discipline vs. application involved. SAR data will provide to geoscientist a powerful terrain visualization of the coastal geology and geomorphology, which can not be acquired from field observations alone. This research has shown the importance of using SAR orbital C and L bands as a fundamental tool for mapping and monitoring purposes in moist tropical coastal environments of the Brazilian Amazon region.

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REFERENCES

ALLINSON, M. A.; LEE, M. T.; OGSTON, A. S.; ALLER, R. C. 2000. Origin of Amazon banks along the northeastern coast of South America. *Mar. Geol.*, n. 163, p. 241-256.

ALLINSON, M. A.; NITTROUER, C. A.; FARIA Jr., L. E. C. 1995. Rates and mechanism of shoreface progradation and retreat downdrift of the Amazon river mouth. *Mar. Geol.*, n. 125, p. 373-392.

BARBOSA, M. P.; SINGHROY, V.; SAINT-JEAN, R. 1999. Mapping coastal erosion in Southern Paraíba, Brazil from RADARSAT-1. *Can. J. Remote Sensing*, n. 25, p. 323-328.

BEMERGUY, R.L. 1981. *Estudo sedimentológico dos paleocanais da região do Rio Paracauari, Ilha de Marajó – Estado do Pará.* Tese (mestrado), Universidade Federal do Pará, Centro de Geociências. Belém.

COSTA, M. P. F.; NIEMANN, O.; NOVO, E. M. L. M.; AHERN, F.; MANTOVANI, J.E. 2002. Biophysical properties and mapping of aquatic vegetation during the hydrological cycle of the Amazon floodplain using JERS-1 and RADARSAT. *Int. J. Remote Sensing*, n. 23, p. 1401-1426

COSTA, W. J. P. 1997. *Sedimentação recente e condições físico-químicas das águas do Lago Novo – Cabo Norte/AP.* Tese (mestrado), Universidade Federal do Pará, Centro de Geociências.

JOHANNESSEN, J. A. 2000. Coastal observing systems: the role of synthetic aperture radar. *Johns Hopkins APL Tech. Dig.*, n. 21, p. 7-14.

KJERFVE, B.; PERILLO, G. M. E.; GARDNER, L. R.; RINE, J. M.; DIAS, G. T. M.; MOCHEL, F. R. 2002. Morphodynamics of muddy environments along the Atlantic coasts of North and South America. In: HEALY, TR; WANG, Y.; HEALY, J-A. (eds.). *Muddy Coasts of the World: Processes, Deposits and Functions*. Amsterdam: Elsevier Science, p. 479-532.

LEWIS, A. J.; HENDERSON, F. M.; HOLCOMB, D. W. 1998. Radar fundamentals: the geoscience perspective. In: HENDERSON, F. M.; LEWIS, A. J. (Eds.). *Principles and Applications of Imaging Radar. Manual of Remote Sensing*. 3 ed. New York, J. Willey, p. 131-180.

LIMA, M. I.; COELHO, F. A. J. F.; SILVA, G. H.; BEZERRA, P. E. L.; FAUSTINO NETO, M.; MIRNADA, C. A.; FERREIRA, J. D. A. 1996. Interpretação morfoestrutural da região leste da Ilha de Marajó (PA). In: *Simpósio de Geologia da Amazônia*, *5*. Resumos. Belém, SBG-Núcleo Norte, p. 327-330.

LOPES, A.; TOUZI, R.; NEZRY, E. 1990. Adaptive speckle filters and scene heterogeneity. *IEEE Trans. Geosci. Remote Sensing*, n. 28, p. 992-1000.

NASDA/MITI, 1996. *JERS-1 SAR Global Rain Forest Mapping Project, South America, 1995-1995*. v. AM-1. Tokio, NASDA. CD-ROM.

PCI. 1999. *EASI-PACE User's Manual*. version 6.3. Ontario, PCI Enterprises.

PLAZIAT, J. C.; PROST, M. T.; BALTZER, F.; RUDANT, J. P. 1994. Specificities of exposed shoreline: mangals in French Guiana. In: *International Sedimentological Congress*, 14. Proceedings… Recife, IAS, p. D69-70.

ROSENQVIST, A. 1996. The Global Rain Forest Mapping Project by JERS-1 SAR. In: *ISPRS Congress*, 18. Proceedings… Vienna, ISPRS, 5 p.

RUDANT, J. P.; BALTZER, F.; DEROIN, J. P.; LOINTIER, M.; MAITRE, H.; MOUGLIN, E.; PÉNICAND, C.; PROST, M. T. 1996. Apport des images radar satellitaires ERS-1 et JERS-1 dans le domaine de la cartographie générale et thématique en contexte tropical humide: exemples en Guyane française et régions limitrophes. *Soc. Fr. Photogramm. Télédetéction,* n. 142, p. 15-33.

SILVEIRA, O.F.M. 1998. *A Planície Costeira do Amapá: dinâmica de ambiente costeiro influenciado por grandes fontes fluviais quaternárias*. Tese (doutorado)-Universidade Federal do Pará, Centro de Geociências, Belém.

SINGHROY, V. 1996. Interpretation of SAR images for coastal zone mapping in Guyana. *Can. J. Remote Sensing*, n. 22, p. 317-328.

SOUZA FILHO, P. W. M.; EL-ROBRINI, M. 2000. Coastal Zone Geomorphology of the Bragança Area, Northeast of Amazon Region, Brazil. *Rev Bras.Geociênc.*, n. 30, p. 518-522.

SOUZA FILHO, P. W. M.; PARADELLA, W.R. 2002. *Recognition of the main geobotanical features in the Bragança Mangrove Coast (Brazilian Amazon Region) from Landsat TM and RADARSAT-1 data*. Wetlands Ecology and Management, n. 10, p. 123-132

SOUZA FILHO, P.W.M. 2000. *Avaliação e aplicação de dados de sensores remotos no estudo de ambientes costeiros tropicais húmidos, Bragança, Norte do Brasil*. Tese (doutorado) - Universidade Federal do Pará, Centro de Geociências, Belém.

TOUTIN, T. 1995. Intégration de données multi-source: comparaison de méthodes géométriques et radiométriques. *Int. J. Remote Sensing*, n. 16, p. 2795-2811.

VITAL, H. 1988. *Estudo do geossistema do Lago Arari, Ilha de Marajó, Pará*. Tese (mestrado)-Universidade Federal do Pará, Centro de Geociências, Belém.

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