Preliminary Evaluation of PALSAR Data for Geoscience Applications in Tropical Environments of Brazil

W. R. Paradella, A. R. dos Santos, C. G. de Oliveira, A. Q. da Silva, C.C.Freitas

National Institute for Space Research (INPE)/Remote Sensing Division (DSR)
São José dos Campos, São Paulo State - 12227-010 – BRAZIL
{waldir, athos, cleber}@ ltid.inpe.br, arnaldo@dsr.inpe.br,corina@dpi.inpe.br

Abstract
The PALSAR imagery with new attributes (distinct polarization, polarimetry and stereoscopy) needs to be evaluated for Geoscience applications in tropical terrains of Brazil. So far, few scenes with three PALSAR modes (FBS-Fine beam single, FBD-Fine beam dual and POL-Full polarimetry), for ascending and descending passes, have been evaluated for test-sites located on the CMP-Carajás Mineral Province (easternmost border of the Amazon Region) and the CRV-Curaçá River Valley (tropical semi-arid area, northeast of the country). Radiometric (adaptive speckle filtering) and geometric (Rational Functions ortho-rectification modeling) corrections and digital image processing techniques (contrast stretch, Principal Component transform, RGB-IHS transform) were applied for the enhancement of FBS and FBD images and for the integration with aerial geophysics. Enhanced value-added products were assessed for geological and structural mapping in the Águas Claras region, for discrimination of iron-mineralized laterites in the N1 deposit; both in CMP, and for lithological discrimination in the CRV. The results emphasized the importance of the look-azimuth, and subordinately, wave polarization in the enhancement of structures and erosional surface features, closely related to bedrock variations. In addition, the possibility of deriving information from POL data, with a better understanding of the role played by scattering mechanisms was preliminary evaluated in the Sossego iron oxide-copper-gold mining area through decomposition target schemes. Although the results are yet very preliminary, they show potential benefits for distinct fields of application in Geosciences. Ongoing work is focusing on the feasibility of topographic mapping using FBS and FBD stereo-pairs (same and opposite-side) for flat and mountainous terrains in the Brazilian Amazon.

Keywords: PALSAR, Geosciences, Brazil, Amazon Region,

1. INTRODUCTION

Brazil has a vast territory with a tremendous need for natural resource assessment, management and monitoring information such as can be provided by orbital SAR data. In view of the territorial extend of the Amazon region with almost 5.5 million km^2, the lack of topographic and geological maps is a drawback for mineral exploration. On the other hand, the northeast semi-arid region (11% of Brazil) also depends on the indirect information provided by remote sensing to support mineral exploration and environmental programs. The advent of PALSAR imageries opens new perspectives to a wide range of applications (topographic, structural and geological mapping for mineral exploration and mining activities, including planning, monitoring and environmental control).

2. BACKGROUND AND CONTEXT

At equatorial latitudes, PALSAR imageries present look-azimuth almost constant and around 80^o for ascending passes, and 280^o for descending passes. For a given look-azimuth, geological structural trends normal to the illumination will be highlighted while topographic features within about 20^o of the look direction can be invisible. Two images taken from opposite-look directions often contain complementary geological information. In addition, radar backscatter is strongly affected by slope effects at small incident angle from 0 to 30^o, by surface roughness at moderate incident angles from 30 to 70^o, and mainly by shadowing at high incident angles from 70 to 90^o. Thus, a variability of look-azimuth and incident angle is necessary for geological applications. In addition, the versatility of PALSAR data with distinct incidence will also allow stereoscopy. Furthermore, SAR images fused with geophysics have provided a powerful tool for geological mapping and exploration in the Amazon [1]. It is important to consider that changes in the polarization of radar waves are object specific and, therefore, an important source of information for discriminating targets in SAR images. A previous study with C-band airborne dual polarization has shown that textural information can be used for mapping of iron-mineralized laterites in CMP [2]. The PALSAR capabilities (multipolarization, polarimetry, stereoscopy) not available in current orbital L-band systems, open new perspectives in Geoscience applications in the tropical environment, mainly for geological and terrain mapping.

3. TEST-SITES

3.1. Carajás Mineral Province (CMP)

The CMP, located on the Pará State, encompasses the world's largest iron deposits and important deposits of Mn

(Azul), Cu (Salobo, Sossego), Ni (Vermelho), among others. The area is part of the Archean Itacaiúnas Shear Belt (ISB), a geotectonical province with metasediments, metavolcanics, gneisses and granulites. Proterozoic activities are represented by anorogenic granitic intrusions and Fanerozoic rocks include extensive lateritic-aluminous covers as well as elluvial, colluvial and alluvial deposits which are gold bearing in many cases. The ISB is characterized by a bundle of WNW-ESE trending structures, with two main lithostructural domains: a set of imbricated ductile oblique thrusts on the southern sector and two strike-slip systems (Carajás and Cinzento) on northern sector. The Carajás strike-slip system is the largest fault system recognized within the ISB. The presence of subvertical E-W trending mylonitic fabric in the basement rocks is a kinematic indicator of a sinistral transpressional event (ca. 2.85 Ga) followed by at least three subsequent cycles of Archean to Proterozoic brittle-ductile strike-slip reactivation, displaying a complex history of movement (> 1 Ga) dominated by oblique and strike-slip displacements [3]. Chemical weathering, thick oxisols, few outcrops and dense rainforest are the main characteristics of the region.

3.2. Curaçá River Valley (CRV)

The CRV is part of a Cu-rich province located on the Bahia State, part of the Salvador-Curaçá belt, a Paleoproterozoic N-S trending, granulite-amphibolite belt in the São Francisco Craton. The lithological units in the region can be grouped as Archean gneisses and granulites interbedded with ferruginous rocks, quartzites, amphibolites, mafic-ultramafic intrusives and Upper Proterozoic marbles/limestones, schists, and phyllites. The gneissic-granulitic complex is cut by Cu-mineralized intrusives with reserves exceeding 150 million tonnes of ore (0.5 to 1.0% average Cu grade). Massive and disseminated sulfides are associated with pyroxenites and weak disseminated sulfides to norites, gabbro-norites and anorthosites. A semi-arid environment with a type-savanna vegetation (Caatinga) is typical in the Valley. The resistance of crystalline rocks coupled with the semi-arid weather, leads to high run-off rates and the rapid removal of weathered material by sheet flooding. Thus, soils are shallow, sandy to clay-rich types with close relationships with the substratum [4].

4. DATASET

This preliminary analysis was based on FBS, FBD and POL PALSAR data (details in tables 1 and 2). The gamma ray data, provided by the mining company CVRD, was acquired in 1993. The helicopter flights were 60 m above the terrain in NW direction and 250 m apart. Previous corrections comprised standard flight altitude, subtraction of the background values from cosmic rays, aircraft contamination, radon background and Compton effect corrections. The gamma data were also processed using simple micro-leveling (high pass filter perpendicular to the flight lines and low-pass filtering along the flight lines before subtraction to the raw grid), followed by interpolation (bi-directional scheme) to regular UTM grid files (60 m resolution, 8-bit format). The units were count per second (cps) for the Total Count (TC), percent for Potassium (% K), and ppm for Uranium (eU) and Thorium (eTh) channels.

Table 1. PALSAR data (CMP)

scene	080153740	076437060	059807060	083147050
product level	1.5	1.5	1.1	1.5
polarization	HH, HV	HH, HV	quad-pol	HH,HV
orbit	Descend.	Ascend.	Ascend.	Ascend.
date	2007/07/27	2007/07/02	2007/03/10	2007/08/17
incidence	38.894º	39.019º	24.310º	39.017º
looks	4 x 1	4 x1	1 x1	4 x1
pixel spacing (m)	12.5 x 12.5	12.5 x 12.5	3.57 x 9.37	12.5 x 12.5

Table 2. PALSAR data (CRV)

scene	025816990	0854770000	081753800
product level	1.5	1.5	1.5
polarization	HH	HH, HV	HH
orbit	Ascend.	Ascend.	Descend.
date	2006/07/20	2007/09/02	2007/08/07
incidence	47.598º	39.035º	38.902º
looks	2 x 1	4 x1	2 x1
pixel spacing (m)	6.5 x 6.5	12.5 x 12.5	6.5 x 6.5

5. RESULTS AND DISCUSSIONS

5.1. Geological Mapping (Águas Claras area)

A (< 50 Mt) Cu-Au-(W-Bi-Sn) deposit occurs in this area, with two proposed models for Cu-Au mineralizations: a genetic connection with the ca. 1.88 Ga A-type Central granite, or inherited from the Archean country rocks, the pluton being responsible for hydrothermal alteration and the re-concentration of the ore elements. These aspects favor target areas in the country rocks near the pluton affected by NW-SE and NE-SW brittle structures, compatible with a model for strike-slip shear zone. This structural arrangement suggests the presence of transtensive structures (Y and T, respectively) like rhomb-chasms, important for the migration of hydrothermal fluids. The structures are controlled by the WNW-ESE oriented regional trend with an inflection to N60W (Carajás fault). The RGB-IHS integration of PALSAR with gamma data produced image patterns with tonal/color variations expressing changes of the bedrock radioelements, while SAR contributed to the enhancement of textural patterns controlled by structures and erosional features (figure 1). Due to distinct viewing geometry, structures striking NW-SE were enhanced under ascending pass, while NE-SW systems were highlighted with descending pass. Two small areas on the NW border of the pluton showed spatial

relationships of enhanced Y, T structures with K anomalies.

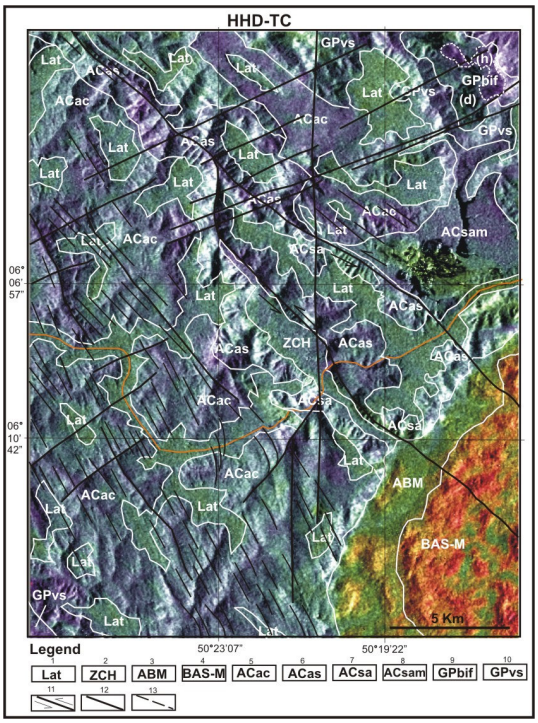

Figure 1. Geological interpretation based on the RBG-IHS integration of PALSAR L-HH with Gamma Total Count (legend: Lat = laterites, ZCH = cataclastic hydrothermalized zone, ABM = amphibole-biotite monzogranite, BAS-M = biotite-amphibole syenogranite-monzogranite, ACac = sandstone, conglomerate, ACas = sandstone, siltstone, ACsa = siltstone, mudstone, GPbif = banded iron formation (h = hematite, d = duricrust), GPvs = metavolcanic, metasedimets, sinistral strike-slip fault, fault, fracture with or not filled by dykes).

5.2. Iron-mineralized laterite mapping (N1 area)

The N-1 is an iron-ore deposit characterized by a plateau (24 km^2) with an estimated reserve of 854 million metric tons with 66.4 % iron concentration. The deposit is related to rocks of the Grão Pará Group (2.7 Ga) subdivided into volcanic rocks (Parauapebas Formation) and the ironstones (Carajás Formation). The ironstones are composed of several types of iron ore from oxide facies. They are mainly jaspelite and interlayered hematite and silica, which are distinguished by hardness (soft hematite, hard hematite, etc.). Under the humid tropical climate of the Amazon region, ferruginous duricrusts and latosoils are extensively developed in the plateau. These weathered products show varying degrees of alteration that are responsible for the differences in composition, hardness and textures. (figure 2a). A specific low-density savanna-type vegetation ("Campus Rupestres") is associated with the deposit and shows a strong contrast ("clearing") with the dense equatorial forest. Principal Component linear transformation (PCT) was used to concentrate the uncorrelated information related to distinct look-azimuth (ascending and descending orbits) taken from PALSAR FBD (L-HH, L-HV) in a color composite image (figure 2b). The comparison of both figures shows the importance of the complementary information (macro-topography and surface roughness variations) provided by PALSAR images taken from opposite-look directions and distinct polarization (like and cross) in the enhancement of tonal/textural patterns closely related to the surface classes, particularly hematite and iron-ore duricrust, which are the most relevant classes in economic context.

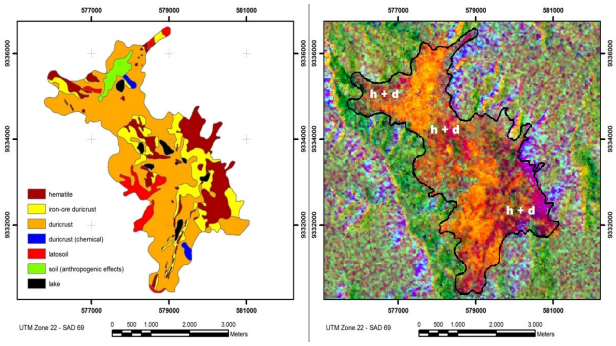

Figure 2:a) Lateritic units in the N1 plateau based on [2], b) PCT color composite (PC1R, PC2B, PC3G) from ascending and descending PALSAR FBD (h + d = hematite + iron duricrust classes).

5.3. Land-cover/land use mapping (Sossego area)

Sossego is an active mine related to one of the most important iron oxide-copper-gold deposit (245 Mt of 1.1% Cu, 0.28 g/t Au) of the CMP. The deposit is related to two major groups of orebodies with distinct alteration assemblages and separated by major high angle structures. The deposit is located along a regional WNW–ESE-striking shear zone, which defines the southern contact between metavolcano-sedimentary units of the ~ 2.76 Ga Itacaiúnas Supergroup and tonalitic to trondhjemitic gneisses and migmatites of the ~2.8 Ga Xingu Complex. The deposit is hosted by granite, granophyric granite, gabbro, and felsic metavolcanic rocks. A PALSAR POL data acquired on March 10, 2007 was converted from SLC to covariance matrix [C], speckle filtered (Lee filter), transformed to coherence matrix [T], and the parameters Entropy (H), Anisotropy (A) and α-angle were computed from the eigenvalues/eigenvectors of [T]. Figure 3a shows the result of target polarimetric decomposition for land-cover and land-use in the mining region using H and α-angle. Figure 3b shows the zones defined by the H/α-angle cartographic features and related physical scattering for the labels of class categories.

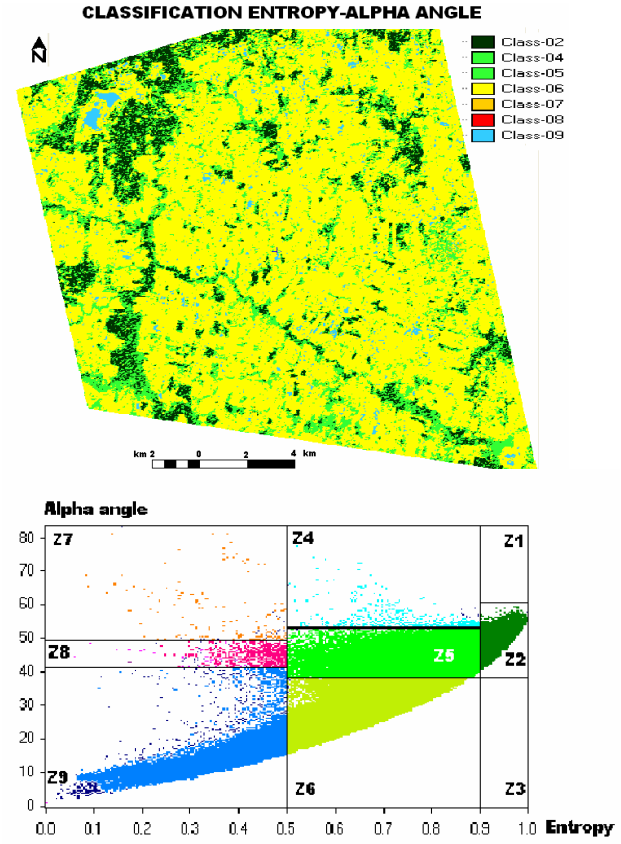

Figure 3. a) Target decomposition for dominant scattering mechanism using PALSAR POL; b) H-α cartographic plan with zones of scattering mechanism related to the categories labels.

5.4. Lithological discrimination (CRV)

Three sets of images were used in this area, two from ascending (FBS-HH, FBD-HV) and one from descending (FBS-HH) passes. The images were radiometrically (speckle filtering) and geometrically (ortho-rectification) corrected, enhanced by linear contrast-stretch, and colors were assigned to the channels. The products (figure 4) allowed the analysis of the spatial variation of rock units, given by different colors and depicting at the same time textural elements due to topographic relief. Since the color composite encompassed radar attributes of changes of polarization, incidence, look-azimuth and time, the analysis highlighted the potential of PALSAR data for geological mapping in the semi-arid environment, when distinct SAR attributes are integrated and fully analyzed.

4. CONCLUSIONS

Although the results are yet preliminary for Brazilian tropical environment, they show potential benefits for distinct fields of applications in Geosciences, particularly Geology and terrain mapping.

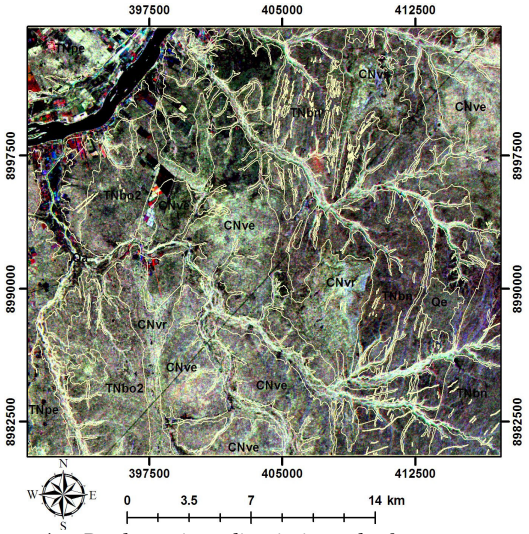

Figure 4: Rock units discriminated from computer enhancement of FBS and FBD data (HHR + HVG* + HHB**). Legend: Qe = elluvium, CNvr =marble, CNve =schist and phyllite, TNbo2 = quatz-feldspar gneiss, TNpe =biotite gneiss, TNbn = biotite-hornblende gneiss. (* Ascend. ** Descend. passes).*

Acknowledgements

The research was conducted under the agreement of JAXA Research Announcement (RA # 219). Special thanks to CNPq for the first author's grant (Process 305542/2006-0).

References

[1] Paradella, W. R.; Santos, A.R.; Veneziani, P.; Sant'Anna, M.V.; Morais, M.C. 2000. Geological Investigation using RADARSAT-1 Images in the Tropical Rain forest Environment of Brazil. Canadian Journal of Remote Sensing, 26, 82-90.

[2] Morais, M. C.; Paradella, W. R.; Freitas, C. C. 2002. An assessment of the discrimination of iron-mineralized laterites in the Amazon region (Carajás Province) based on textural attributes from C-band SAR data. Asian Journ. of Geoinformatics, 2 (3):11-20.

[3] Veneziani, P.; Santos, A. R.; Paradella, W.R., 2004. A evolução tectono-estratigráfica da Província Mineral de Carajás: um modelo com base em dados de sensores remotos orbitais (SAR-C RADARSAT-1, TM LANDSAT-5), aerogeofísica e dados de campo. Braz. Journal of Geosc., 34:67-78.

[4] Paradella, W. R.;Vitorello, I. 1995. Geobotanical and Soil Spectral Investigation for Rock Discrimination in the "Caatinga" Environment Based on Multitemporal Remote Sensing Data. Can. Jour. of R. S., 21 (1): 52-59.

[5] Cloude, S. R.; Pottier, E. 1997. An entropy based classification scheme for land application of polarimetric SAR. IEEE Trans. on Geosc. and R.S., 35 (1): 68-78.