GEOSCIENCE APPLICATIONS WITH L-BAND PALSAR DATA IN THE TROPICAL ENVIRONMENTS OF BRAZIL

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Abstract
For the past three decades a large amount of Synthetic Aperture Radar (SAR) data has been used to a wide range of geoscience applications in Brazil (geology, geomorphology, cartography, etc.). The L-band PALSAR imageries with new attributes (high spatial resolution, distinct wave polarization, stereoscopic and polarimetric capabilities) need to be evaluated for practical application in distinct kinds of tropical terrains. In addition, the possibility of gathering interferometric data to derive altimetric information should also be investigated. Monoscopic, stereoscopic (same/opposite-side pairs) and digital (value-added SAR products, amplitude polarized images, polarimetric signature) analysis will be carried out for terrain mapping in three test-sites: Carajás Province and Bragança coastal plain, both located on the easternmost border of the Amazon Region (Pará State), and Curaçá Valley, a semi-arid area on the northeast of the country (Bahia State).

1. Introduction
Brazil has a vast territory with a tremendous need for natural resource assessment, management and monitoring information such as the one which can be provided by orbital SAR data. In view of the territorial extend of the Amazon region (more than 50% of the national territory), the lack of topographic and geological maps are drawbacks for mineral exploration. In addition, the Amazon coastal zone is also poorly mapped. On the other hand, the northeast semi-arid region (11 % of Brazil) also depends on the indirect information provided by radar remote sensing to support mineral exploration and environmental programs. The proposed high-resolution PALSAR imageries open new perspectives for accurate terrain mapping in these distinct environments. This proposal can be considered as a first step aiming at the use of high resolution L-band SAR data as an effective tool applied to a wide range of applications (topographic and geological mapping for mineral exploration and mining activities, including planning, monitoring and environmental control, etc.).

2. Background and Context
At equatorial latitudes, orbital SAR imageries (ERS-1, ERS-2, RADARSAT-1, JERS-1) present a look-azimuth almost constant and around 80 degrees for ascending passes, and around 280 degrees azimuth for descending passes. For a given look-azimuth, geological structural trends normal to the illumination will be highlighted while topographic features within about 20 degrees 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 degrees, by surface roughness at moderate incident angles from 30 to 70 degrees, and mainly by shadowing at high incident angles from 70 to 90 degrees (JPL 1980, Ford et al. 1998). Thus, a variability of incident angle is necessary for geological applications. In addition, the versatility of PALSAR data with distinct incidence will also allow parallax and stereoscopy. A recent research carried out in Carajás Province with RADARSAT-1 Standard pairs (same-side and opposite-side viewing) showed that the stereoscopy has increased the geological interpretability when compared to the monoscopic analysis, mainly in the definition of low-angle dipping strata, lithological contacts and general discontinuities (Santos et al. 1999). Thus, the stereo PALSAR is an interesting radar geological issue to be investigated in the tropics. SAR digital images (SAREX' 92, JERS, and RADARSAT-1) integrated with aerogeophysical data (gamma and magnetics) have provided a powerful tool for geological mapping and exploration in the Amazon (Paradella et al. 1997). 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 recent study based on C-band airborne dual polarization data has shown that information derived from textural attributes can be used for preliminary iron-mineralized laterite mapping in areas with sparse savanna-type vegetation in the Carajás (Morais et al. 2002). For coastal zone terrains, C-HH (RADARSAT-1) and X-HH (GEMS 1000) imageries have been evaluated for geological and geomorphologic mapping, land-cover assessment and for evaluating severe coastal changes occurring in the Bragança coast (Pará State) over the last three decades (Souza-Filho & Paradella 2003). In summary, the new PALSAR capabilities (L-band high spatial resolution, distinct polarization and polarimetry) not available in current SAR systems need to be evaluated in the tropics for terrain mapping. A fundamental step in this task is understanding the mechanisms by which microwave signals interacts with surface components. In tropical semi-arid environments, such as in the Curaçá Valley (northeast Brazil), weathering signatures (lateritic soil

development, fracturing, debris grain size and shape, hill slope characteristics) are controlled in a large extent by lithologic characteristics of the parent bedrock. Additionally, the dry savanna "Caatinga" vegetation, typical in this environment, presents closer relationships in terms of density and floristic variations with the changes of the substrate, defining important geobotanical controls (Paradella & Vitorello 1995). These relationships favor studies where the role of each primary member (rock-soil-vegetation) can be characterized through signatures related to scattering mechanism extracted from polarimetric experimental PALSAR data. The limits to which such innovations can add to the conventional capabilities for radar geology remain to be demonstrated (Ford et al. 1998).

3. Proposal General Objectives

The general objectives of the investigation are:

(1) To evaluate the use of PALSAR distinct look-azimuth and incident angles for tectonic, structural and geological mapping in the dense rainforest mountainous environment of the Carajás Province through monoscopic and stereoscopic analysis (opposite and same-side pairs;

(2) To evaluate value-added digital products based on PALSAR and aerogeophysical data for geological mapping in the Carajás Province;

(3) To investigate the potentiality of textural attributes derived from high-resolution PALSAR (HH, VV, HH+HV) for discriminating iron-mineralized laterites in the Carajás Province;

(4) To investigate the use of the PALSAR distinct look-azimuth (opposite-side) and incident angles (steeper viewing) in the geological characterization of flat, low-relief terrain related to the Curaçá River Valley through stereoscopic analysis;

(5) To evaluate the role of the polarization (HH, VV, HH + HV) and experimental polarimetric (quad-pol) PALSAR data in the characterization of surface changes (rock-soil-vegetation) in the Curaçá Valley;

(6) To investigate the potential of PALSAR attributes (look-azimuth, variable incident angles, distinct polarization and polarimetric data) in the terrain characterization (geology, geomorphology, land-cover assessment) through a multitemporal series of acquisition on a macrotidal mangrove coast in the Amazon region (Bragança Coastal Plain).

4. Test Sites

4.1. Carajás Mineral Province.

The Carajás Province encompasses the world's largest iron deposits and important deposits of Mn (Azul), Cu (Salobo, Sossego), Ni (Vermelho), among others. The area, with a heterogeneous relief (altitudes from 250 up to 800 meters) is part of the Archean Itacaiúnas Shear Belt, 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. Chemical weathering, thick oxisols ("latosols"), few outcrops and thick tropical rainforest are some of the main characteristics of the region. Due to the economic importance of this area there is an increasing need to provide accurate maps to support exploration and also environmental programs. A reasonable amount of airborne and orbital SAR data with distinct characteristics (frequency, polarization, viewing geometry, resolution) has been acquired over the area during the last decade and will be available for investigation (INTERA, ERS-1, JERS-1). The Province was also the test-site for two large C-band SAR programs: SAREX'92 and ADRO.

4.2. Curaçá River Valley

The Curaçá River Valley, a Cu-rich province is characterized by a land surface worn down by erosion to a nearly flat plain (altitudes from 350 up to 430 meters). In this pediplain, the altimetric variation among watersheds is approximately 20 meters. The area is associated to a semi-arid climate with 500-700 mm of rainfall mainly restricted to the summer (Jan-Feb-Mar). The extraction of geologically related information from optical remote sensing was favored by sparse to regular dense Caatinga vegetation, with marked seasonally, shallow residual soils closely related to the substratum, and frequent occurrences of rock exposures. The lithological units found in the area can be grouped in Archean gneissic and granulitic associations, interbedded with ferruginous rocks, quartzites, amphibolites and mafic-ultramafic intrusives and a sequence of Upper Proterozoic metasediments (marbles, limestones, schists and phyllites). These units show structural grain (foliation) with N-S trending, and metamorphism ranging from greenschists to granulite facies, typical of the Archean/Proterozoic mobile belts. The region was selected in the past as the Brazilian test-site for the SPOT-1 evaluation in the PEPS Program (Paradella & Vitorello 1995).

4.3. Bragança Coastal Plain

The Bragança coastal plain is extremely irregular and jagged with a low gradient coast. A continuous mangrove belt of around 20 km wide fringes the shoreline with elevation from 1 up to 2 m above mean tide level. A wet season from December to May and a dry season from June to November mark the climate. The average annual rainfall reaches 2,500 mm and the mean tidal range is around 5 m on a semi-diurnal cycle. Large areas of the low lands are flooded during spring tides due to both rainfalls with high runoff rates and tidal effects. On one hand, strong tidal currents from east to west and waves 1.5 m high are responsible for the erosion of mangroves along the coast, estuaries and bays, where lines of fallen mangrove trees mark the eroded sites. The application of previous SAR data (RADARSAT, GEMS) integrated with TM-Landsat data has allowed to characterized nineteen coastal features in this area: estuarine channels, submerged sand banks, sandflats, old estuarine sandbanks, mudflats, ebb-tidal deltas, barrier-beach ridges, coastal dunes, chenier sand ridges, young intertidal mangroves, intertidal and supratidal mangroves, outer and inner marshes, fluvial flood plains, coastal plateau, degraded and regenerated mangroves, and an artificial lagoon (Souza Filho & Paradella 2002).

5. Requested Data-Set

Based on the ALOS basic observation scenario as presented by JAXA during the 2nd ALOS PI meeting, it was necessary to change the original proposal (# 219). Thus, and in order to accomplish the objectives of the investigation, PALSAR data should be acquired under the following configurations:

Test Site # 1	**Carajás Province**
Sub-area: Águas Claras	**S 06 ° 10'/ W 50° 20'**
Acquisition Modes * = ascending pass, ** = descending pass cycle = acquisition period I = INSAR total: 10 scenes	FBS HH 34.3^0/cycles 7-8 * FBS HH 43.4^0/cycles 9-10* FDB HH+HV 34.3^0/cycle 5*(I) FDB HH+HV 34.3^0/cycle 6* (I) FDB HH+HV 43.4^0/cycles17-18* ScanSAR HH/cycles 5-9** FBS HH 34.3^0/cycles 10-11** FBS HH 43.3^0/cycles 10-11** FDB HH+HV 34.3^0/cycles 18-19** FDB HH+HV 43.4^0/cycles 18-19**
Sub-area: Sossego	**S 06 ° 25'/ W 50 ° 05'**
Acquisition Modes * = ascending pass **= descending pass cycle= acquisition period total = 06 scenes	FBS HH 34.3^0/cycles 7-8 * FBS HH 43.4^0/cycle 9* FDB HH+HV 34.3^0/cycle 5* FDB HH+HV 43.4^0/cycle 17* FBS HH 34.3^0/cycles 10-19** FBS HH 43.3^0/cycles 10-19**
Test Site # 2	**Curaçá Valley**
coordinates	**S 09 ° 10′/ W 39° 50′**
Acquisition Modes * = ascending pass, ** = descending pass cycle= acquisition period total: 10 scenes	FBS HH 21.5^0/cycles 7-11 * FBS HH 34.3^0/cycles 7-8 * FBS HH 43.4^0/cycles 9-10* FDB HH+HV 34.3^0/cycle 5* (I) FDB HH+HV 34.3^0/cycle 6* (I) FDB HH+HV 43.4^0/cycles 17-18* Pol. 21.5 (quad)/cycles 11-20* ScanSAR HH/cycle 7** FBS HH 21.5^0/cycles 5-9** FBS HH 34.3^0/cycles 5-9 ** FBS HH 43.3^0/cycles 5-9**
Test Site # 3	**Bragança**
coordinates	**S 01 ° 00'/ W 46° 74'**
Acquisition Modes * = ascending pass, ** = descending pass cycle= acquisition period total: 11 scenes	FBS HH 21.5^0/cycle 11 * FBS HH 34.3^0/cycle 8 * FBS HH 43.4^0/cycle 9* FDB HH+HV 34.3^0/cycle 5* (I) FDB HH+HV 34.3^0/cycle 6* (I) FDB HH+HV 43.4^0/cycles 17-18* Pol. 21.5 (quad)/cycles 11-20* ScanSAR HH/cycles 5-6** FBS HH 21.5^0/cycles 10-19** FDB HH+HV 34.3^0/cycle 10-11* FDB HH+HV 43.4^0/cycles 10-11*

6. Methodology

PALSAR images will be visually interpreted (mono and stereoscopic analysis). Amplitude data will be speckle suppression corrected through PCI's radar analysis package. The ortho-rectification of the images for the test-sites will be carried out depending on the implementation of the PALSAR option in the commercial software (PCI Geomatics) or geometric corrected through polynomial transformation based on GCPs from field. Digital integration with geophysical data will be based on IHS transform and visually interpreted. The texture analysis will be based on Grey Level Co-occurrence Matrix (GLCM). Polarimetric data will be processed and amplitude images, polarization response plots, phase difference images, etc., and scene statistics will be extracted to better characterize distinct types of terrains.

7. Anticipated Results

The general purposes of the investigation are to evaluate the potential and to establish practical limits in terms of the usage of the PALSAR data as an effective tool aiming at geoscience applications in distinct terrains of tropical environments.

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