CO-389

# TOPOGRAPHIC AND FORESTRY MAPPING FROM BRAZILIAN AMAZON USING SYNTHETIC APERTURE RADAR IMAGES

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## 1. INTRODUCTION

The Amazon is a region of great economic and strategic interest for Brazil, covering a total area of 5.2 million km$^2$, which about 1.8 million km$^2$ has no appropriate and updated land mapping information at scales larger than 1:250,000 and is usually called the "Cartographic Blank of the Amazon". The poor existing mapping consists of cartographic documents that do not represent the features planialtimetric at ground level, but at the level of the forest canopy. The technological solution to enable the mapping of land located under the constant cloud cover and dense rainforest canopy, with minimum effort to field support, is based on the combined use of Synthetic Aperture Radar (SAR) Interferometry (InSAR), in P band, which allow penetration into the canopy and the interaction of the wave at the ground level, with geo-positioning systems (GPS) and inertial navigation.

The good results obtained recently in cartographic applications based on the use of interferometric radar technology, in X and P bands (DSG, 2000, DUTRA et al., 2002), besides the great interest in the mapping of Amazon, were decisive for the approval in 2008, the Project of Implantation of the Amazon Mapping System. The Management and Operational Center of the Amazon Protection System (CENSIPAM, 2008) administrates the activities of this project, whose implementation was decentralized to the Brazilian Army, Navy, and Air Force and to the Geological Service of Brazil. These institutions are already working in the development of three subprojects to construction of the terrestrial, nautical and geological maps of that region.

The Terrestrial Cartography Subproject, also known as "Amazon Radiography", under the responsibility of implementing the Geographic Service of the Brazilian Army (DSG), aims at the development of approximately 20,000 cartographic products (topographic maps, orthoimages SAR, Digital Elevation Models, etc) and forestry stratification at scales of 1:100,000 and 1:50,000, mapping the "Cartographic Blank", broken down as follows: the planialtimetric mapping of 1,142,000 km$^2$, in areas of dense tropical forest (Figure 3a), based on airborne InSAR, in X and P bands; and planialtimetric mapping of 658,000 km$^2$, in non-forest areas (grasslands and disturbed areas), based on airborne InSAR, in X and L bands.

In this context, the purpose of this paper is to show the methodologies and the preliminary results for the airborne synthetic aperture radar (SAR), in X and P bands, field support and the feature extraction and cartographic production for forestry and topographic mapping, on the 1:100,000 and 1:50,000 scales, which is being used for mapping forestry areas in the "Amazon Radiography".

## 2. AIRBORNE SAR AND FIELD SUPPORT METHODOLOGIES

### 2.1. Aerial Reconnaissance

The purpose of this step is to choose the likely sites without vegetation and with access by boat for the installation of trihedral corner reflectors, which have been used during the step of pre-signaling radar flight. Based on aerial reconnaissance it is possible to minimize the efforts needed to carry out the field support, which was fully adapted to the logistical and natural difficulties of the Amazon region.

### 2.2. Determination of Reference Stations

The purpose of this step is the selection and determination, before flight, of high precision planialtimetric coordinates, by measuring DGPS, of support points (reference station) to radar flights. These points are materialized on airfields defined as operations bases through the transport of coordinate points from the Brazilian Network for Continuous GPS Monitoring (RBMC). Concurrent with the flight, these stations (ground segment), are occupied with geodetic DGPS receiver, with the purpose of processing, after the flight, the inertial system data and DGPS flight segment, in order to obtain the position and orientation of a certain point of the antenna beam with an accuracy of approximately 5 cm.

### 2.3. Pre-Signaling Radar Flight

This step is characterized by the installation of corner reflectors, which are used as control points and signaling to the radar flight. The use of control points is the most accurate way for determining the offset of the interferometric phase. Usually, it is used as the control point in the radar image, a corner reflector, which is the most common form of a triangular trihedral (CURLANDER and MCDONOUGH, 1991) of metallic material, whose size depends on the wavelength used by the radar. To generate a control point, the planialtimetric coordinates of the corner reflector vertex are measured by DGPS tracking.

In the context of the "Amazon Radiography" it is performed the determination of high precision planialtimetric coordinates of the vertex of nine trihedral corner reflectors formed by triangles of aluminum with sides measuring 1.41 m, 2.00 m and 1.41 m. These reflectors are installed before the radar flight with the goal of being used as control points (Figure 1c) in the calculation of the interferometric phase offset. These set of nine reflectors are installed at sites without vegetation (Figure 1a) or above of aquatic platforms (Figure 1b), with intervals from 300 to 1200 m along the radial direction of flight, and positioned, on average, every 120 km along the flight line (Figure 3b).

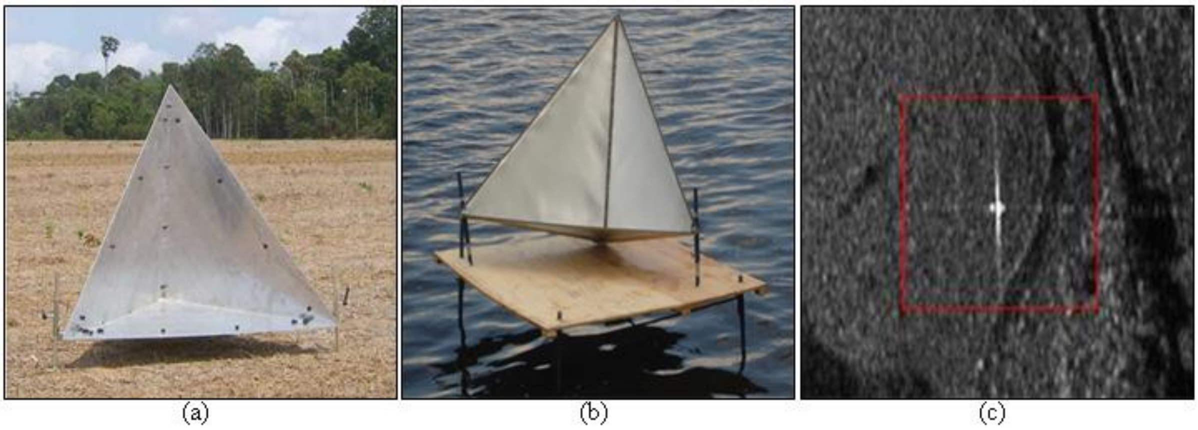



*Figure 1 - Reflector installed in (a) an ideal place and (b) an aquatic platform and (c) example of a typical signal of a reflector in a SAR image.*

### 2.4. Airborne SAR

In this step it is executed the SAR imaging to obtain radar raw data from dense forest areas, where is used the imaging system OrbiSAR airborne-RFP designed and built by Orbisat da Amazônia Company. This system was designed to operate with flight and ground segments (reference stations). The flight segment (Figure 2) consists of a SAR sensor in the X (9.65 GHz) and P (0.415 GHz) bands, installed on board an aircraft TURBO COMMANDER, navigation system with measurement equipment of the position (Omnistar DGPS), with absolute accuracy of 1 m in real-time, and orientation of the aircraft (Inertial Measurement Unit), with angular accuracy to hundredth degree, and flight control, which calculates the deviation of the aircraft in relation to planned line.

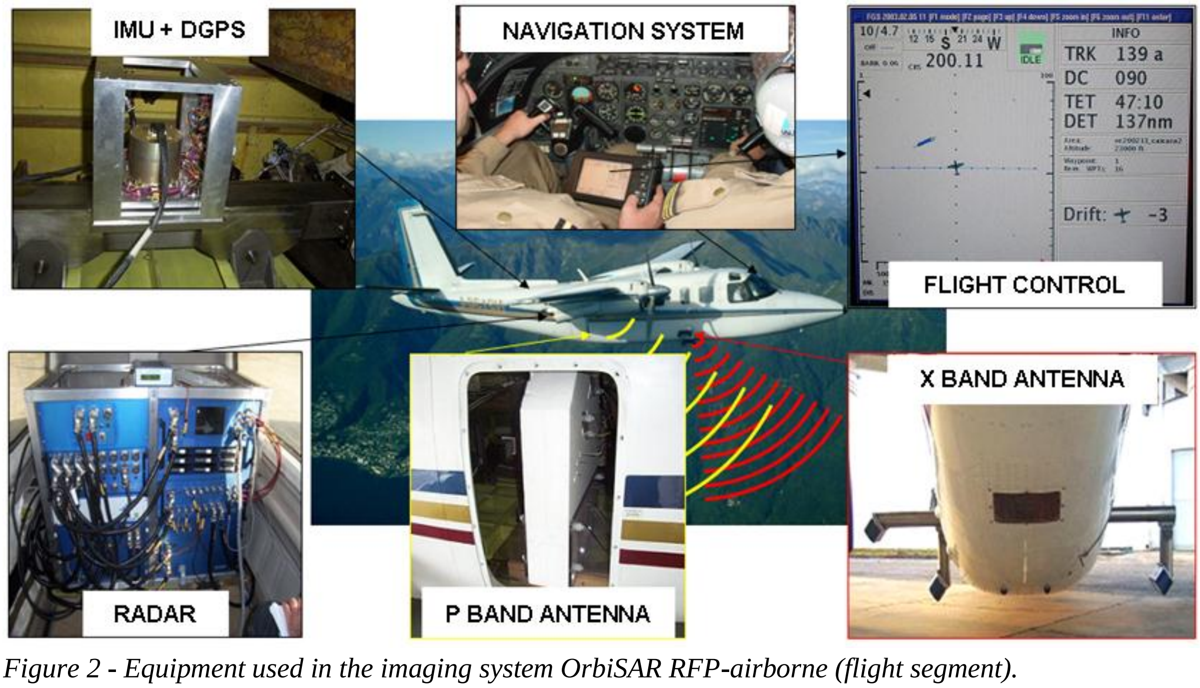



*Figure 2 - Equipment used in the imaging system OrbiSAR RFP-airborne (flight segment).*

To minimize the influence of weather and operational problems on any aerial survey conducted in the Amazon, and to maximize the daily production of the flights, the area to be flown was divided, whenever possible, in blocks of 1° x 1° of latitude and longitude (Figure 4b). This flight procedure comprises the following steps: first, in order to enable georeferencing of SAR images of the tracks in the east to west direction, the imaging tracks from north to south (Figure 3c), called corners track, with width of 14 km (radial direction) and length up to 220 km (azimuth direction), which includes the reflectors that were installed prior to flight, are flown (Figure 3b); secondly, the tracks in the east to west direction (Figure 3d), with radial width of 14 km and length up to 180 km, which cover the area to be mapped, are flown.

To ensure the planialmetric precision for the cartographic products of the project presented here, it will be necessary to distribute for the whole area of 1,142,000 $km^2$ of the Cartographic Blank, a total of 102 set of corners, which means the GPS measurement of 918 control points. Initially, it may seem a large number of points to be raised. However, taking into account that less than 3 GPS points for each map on the 1:100,000 scale will be measured, representing an area on the ground of the order of 3,025 $km^2$, it is concluded that the total number of points is very small for the size of the area to be mapped.

This reduced number of GPS points to be measured, which allowed the reduction of the project costs, was due to the field support methodology developed and the recent adoption of a new method of interferometric phase calibration developed by MURA (2000), called as autocalibration. The new method aims at automatically determining the offset of the interferometric phase without the use of reflectors. For this reason, it is necessary to acquire interferometric SAR images from a certain area on the ground, covered with distinct position. Therefore, the flight methodology described earlier was not affected, only with the completion of the corners tracks imaging in both ascending (northbound) and descending flight (southbound), which imply the reduction of the set of corners that will be installed. Based on the first results obtained with the method of autocalibration, the intention is to employ the reflector just as planialtimetric control points of the project and not anymore as points required for performing of the interferometric phase calibration.

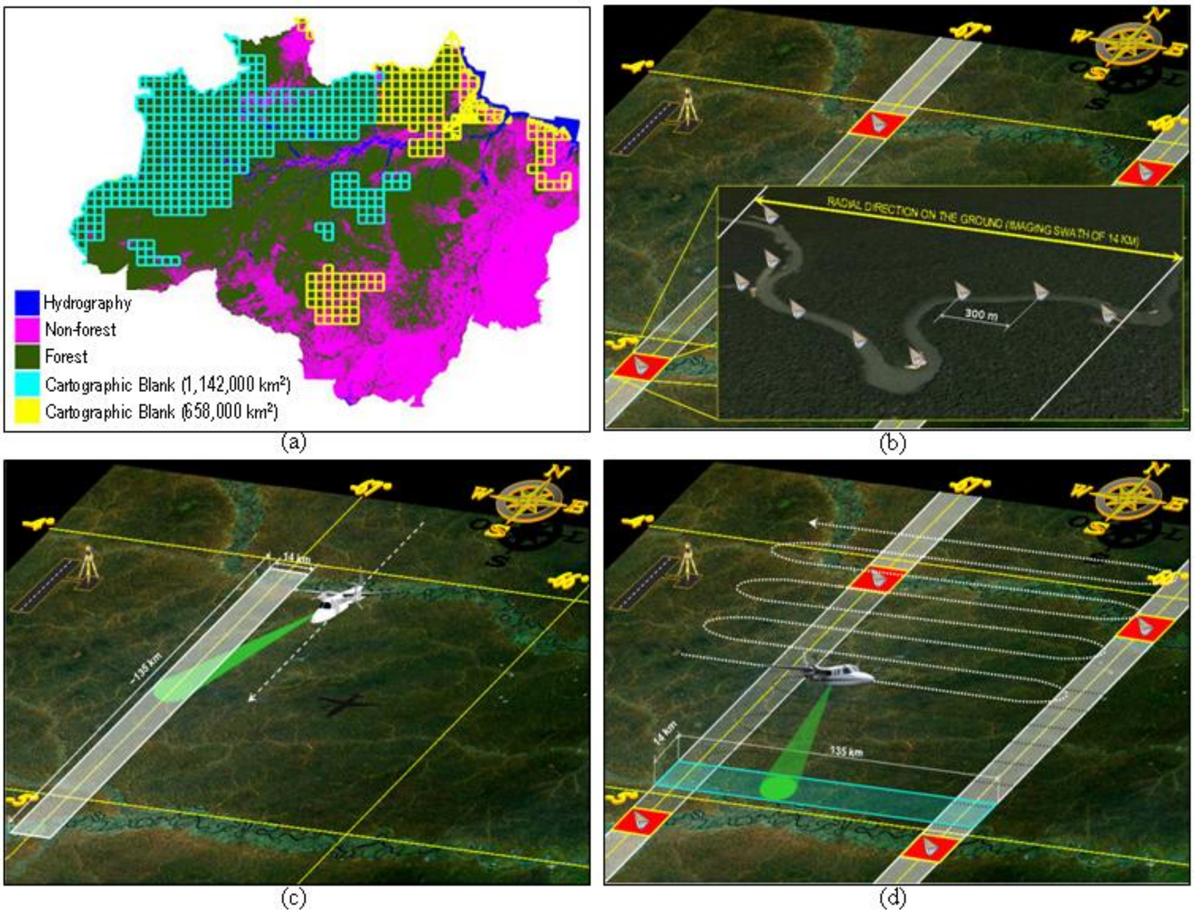



*Figure 3 – (a) Cartographic Blank of the Amazon in the scale of 1:100,000 and methodologies of (b) pre-signaling radar flight and SAR imaging in (c) north-south and (d) east-west directions.*

**2.5. Transcription of Radar Raw Data**

This step is performed immediately after the daily flight campaign. The purposes of this step are the validating of the quality of the acquired data and generation of the original radar data and the navigation system data for each flight line from the mapped area. For this reason, it is used a transcription portable system which allow realize the following operations: conversion of the raw data to the standard format of SAR processing; performance the quality analysis of different variables from the system sensor (eg, intensity and phase the signal transmitted and received by the radar, coherence, position and orientation of the aircraft); and generation of SAR images to small portions of each flight line.

## 3. METHODOLOGY FOR CARTOGRAPHIC PRODUCTION

### 3.1. SAR Raw Data Processing

This step consists of the input data generation, with a spatial resolution of 5 m, which are used in the next stages of the cartographic production. In the first stage of the SAR processing, based on the radar raw data, pairs of monopolarized images are generated in X band (HH), and multipolarized images, in P-band (HH, HV and VV), both in the single-look complex (SLC) format. These complex images are used to generate SAR orthoimages, interferometric coherence images, Digital Surface Models (DSM) and Digital Terrain Models (DTM). These digital models represent, respectively, the altitude variations at the level of the forest canopy (X band) and at ground level (P band), even in areas of dense forest.

### 3.2. Extraction of Cartographic Features

This step is based on the application of techniques from digital image processing and visual interpretation of images to the acquisition of cartographic features of vegetation, hydrography, altimetry and planimetry, as described below, using the different inputs data described in Table 1.

*Table 1. Description of input data for the extraction of the classes of interest.*

| № | Code/Band | Description |
|---|---|---|
| 1 | ORI X-HH | Orthoimage in amplitude of HH polarization from X band |
| 2 | ORI P-HH | Orthoimage in amplitude of HH polarization from P band |
| 3 | ORI P-HV | Orthoimage in amplitude of HV polarization from P band |
| 4 | ORI P-VV | Orthoimage in amplitude of VV polarization from P band |
| 5 | COH X | Interferometric coherence image from X band |
| 6 | COH P | Interferometric coherence image from P band |
| 7 | DSM | Digital Surface Model from X band |
| 8 | DTM | Digital Terrain Model from P band |

#### 3.2.1. Vegetation

The extraction of the thematic classes of vegetation, which include the land use and land cover classes, involves the application of the techniques of principal components transformation, segmentation and classification. The definition of forest formations used in the classification stage is based on information from thematic maps phyto-ecological of RADAMBRASIL Project (BRASIL, 1978) such as: grassy-woody tree, grassy-woody shrub, flooded forests and forests for firm ground. Other classes of interest are related to disturbed areas (secondary forest, cultivation, grazing, etc).

The method of obtaining the vegetation features is based on the processing of the main components of all images presented in Table 1, using the Feature Extraction Tool of the ENVI Zoom module belong to ENVI software (ITT, 2008), according to the results described in Section 5.3. The classified image is edited with the elimination of areas not representable in the scale of work, the inclusion of small areas that were not discriminated by the classifier and the redefinition of pixels to their true class.

#### 3.2.2. Altimetry

The extraction of the altimetric features is based on the corrected DTM from the some errors occurred during the SAR processing stage. The corrected DTM is sliced at intervals of 10 m for the extraction of altimetric features of the line type, corresponding to the land contour with equidistance equal to that interval. Then, smoothing is performed of the vectors to eliminate the appearance of jagged lines, which follow the square shape of the pixel. In addition to the contour lines, the DTM is used for extraction the altimetric features of the point type which are captured in places where it is necessary to know the altitude of the terrain (eg, hills, dips and flat regions).

#### 3.2.3. Hydrography

Using the corrected DSM and DTM from the some errors occurred during the SAR processing stage, a mask is constructed considering the pixels with values equal to the dummy data (-9999), corresponding to the areas where the signal by backscattering targets barely returned to the radar and was lost for specular reflection (regions of water bodies, for example) or non-imaged areas (regions of shadow to the radar signal). After the filtering, the elimination of non representable areas in the scale of the work and polygon smoothing mask, the hydrographic features of the polygon type are obtained. The extraction of hydrographic features of the line type is performed semi-automatically by the software RiverTools (RIVIX, 2009), which considers the direction of drainage flow and drainage flow accumulated in each cell of the DTM.

After the semi-automatically extraction of the drainage network, the vectors that characterize the linear hydrographic feature should be analyzed. These vectors must agree with the contour line already extracted and with the hydrographic features of the area type. Such compatibility should be carried out by the intervention of an experienced operator, using the editing tools found in the work platform.

#### 3.2.4. Planimetry

Currently, there is no application that automatically identifies, with satisfactory results, planimetric features of the line type on the images. Thus, the visual interpretation method is employed to extract the features of planimetry, placing the SAR orthoimages as background for the operator scan in the screen the features of interest (eg, roads that are easy to identify the image, limits of new urban areas originated from localities, villages and towns, new roads and airfields).

### 3.3. Field Work

This step consists of the data collecting in field of the places name, the information and data relating to natural and man-made features of the terrain and the confirmation of the correspondence between features interpreted by the operator or classified by digital processing techniques and the truth on the ground. Besides, the determination of high precision planialtimetric coordinates is performed by measuring DGPS with topographic survey. It is determinate the features not identified on the images and irregular grids containing at least 100 ground control points in forest and non-forest areas, to classify the cartographic products according to Standard Cartographic Accuracy (CONCAR, 1984).

### 3.4. Elaboration of the Cartographic Products

It is the last stage of the cartographic production when we perform the validation of the acquired geometric and topological elements, along with vector editing, construction of the map layout, insertion of place names, legends and marginal information and layout of the cartographic product, according to legal norms in Brazil prepared by the DSG and certified by the National Commission of Cartography (CONCAR, 2009).

The methodology presented here, which will also be used in the topographic mapping of of 658,000 $km^2$ in non-forest areas, will allow about 20,000 cartographic products on the 1:50,000 and 1:100,000 scales composed by: SAR orthoimages in X, L and P bands; color SAR orthoimages with hydrographic and altimetric layers overlaid; DSM; DTM; topographic maps; Digital model of the forest height; Digital files of forestry stratification, land cover and land use; and continuous base of vector data for application in a wide spectrum of geographic information systems.

## 4. METHODOLOGY FOR FORESTRY STRATIFICATION

The step of forestry stratification aims at elaborating the forestry inventory and will be based on the methodology proposed by LEDUC (2007), with the following objectives: structural analysis of the species present in the area inventoried; estimating the importance of each morphospecies in the community forestry, through estimates of abundance, frequency, relative dominance and importance value index, and quantification of the number of individuals, basal area, merchantable volume and biomass above ground.

From the digital archives of vegetation obtained in the previous step, areas of interest will be pre-selected for implementation of the methodology of forestry inventory, whose the distribution of samples per land cover class is shown in Table 2. Because of the dimensions area of the "Cartographic Blank of the Amazon" that are being mapped, only after obtaining thematic maps of land cover is that will be possible to set the sampling rate which will depend also on the variability of the population, priority for the area to be mapped and the time and resources available for the inventory.

*Table 2. Samples distribution per class of land cover.*

| Forestry Class | Area (ha) | Sample Structure | Dimension |
|---|---|---|---|
| Dense forests for firm ground | 6 | Cross of Malta | 4 de 10 x 250 m |
| Dense forests for firm ground explored | 6 | Cross of Malta | 4 de 10 x 250 m |
| Secondary forest | 2 | Rectangular | 10 x 200 m |
| Secondary succession | 1,5 | Rectangular | 10 x 100 m |

At the final stage of the forestry inventory, based on data of forest species identification and measurement of variables dendrometric collected in the field, the following products will be obtained: structural analysis of the forest; statistical analysis; listing of the forestry species; number of trees per species per hectare; basal area and volume per species per hectare; and a forest inventory report. The necessary field work to perform the forestry inventory will begin only in the middle of 2011 due to the limited amount of SAR images that were processed up to now, according to the results described in the Section 5.2.

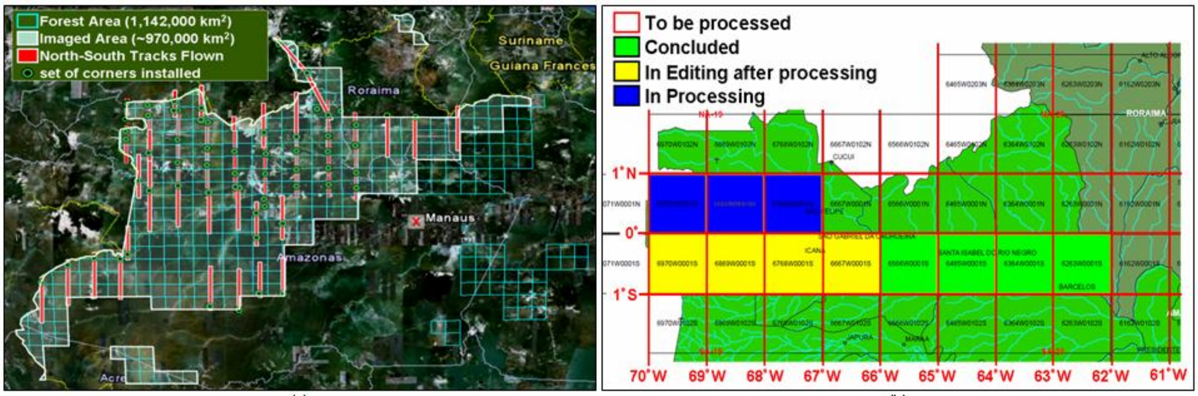
## 5. RESULTS

### 5.1. Airborne SAR and Field Support

Until now, the airborne SAR step of the project, that began in September 2008, resulted in the coverage of about 970,000 km$^2$ of dense forest (Figure 4a), besides the 62 set of corners already installed and their respective north-south tracks already flown, which has produced a volume of raw data stored in 550 hard drives of 1 TB (originals and copies). With the simultaneous use of two aircrafts in early 2011 by the end of the first semester of 2011, the SAR imaging of the remaining area of 172,000 km$^2$ will be completed. This corresponds to the flight lines east-west. With the increase in teams to install reflectors and with consolidation of the autocalibration methodology described in Section 2.4, it is intend to conclude the field support and imaging of the north-south tracks by the end of 2011. This anticipates in 12 month the deadline for conclusion of the airborne SAR.

### 5.2. SAR Processing

The stage of radar raw data processing to generate the inputs of the project (orthoimages, DSM and DTM) is inserted in a process of technology transfer from Orbisat Company to DSG. Because of the minimum time required for training the people involved in this stage and to delays in assembling the processing structure of DSG, just four blocks have been fully processed, from March 2010 until the present moment. This is equivalent to the generation of these inputs to an area of only about 48,400 km$^2$, as shown in Figure 4b. In 2011, we intend to achieve the goal of 3 blocks per month, with the aim of concluding by 2014, all processing area of 1,142,000 km$^2$.

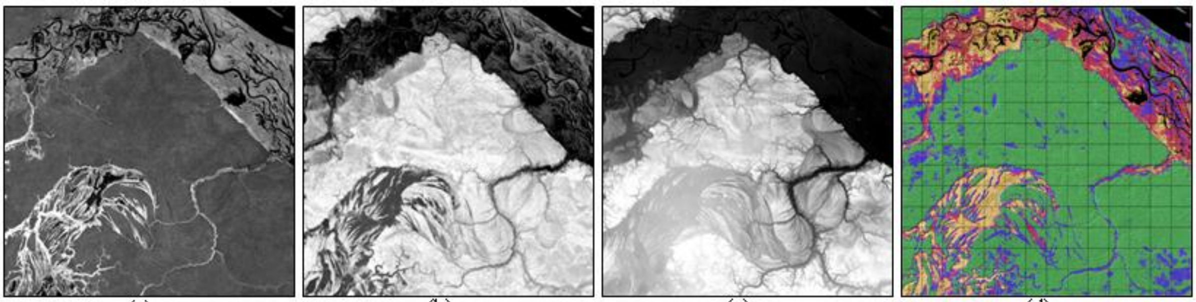



(a) (b)

*Figure 4 - Current Status of the steps of (a) airborne SAR and (b) blocks processing related to areas of dense tropical forest of the "Amazon Radiography".*

### 5.3. Elaboration of Cartographic Products

To illustrate the first results obtained with the method of extraction of cartographic features described above, we selected the study area located between latitudes 00° 45' S and 01° 00' S and longitudes 63° 00' W and 63° 15' W, from an northwest area of the urban center of Barcelos town, in Amazon state of Northern Brazil. In the Figure 5a the P-HH band image of this area is presented. This corresponds to the map on a scale of 1:50,000 from systematic mapping of Brazil. Initially, we obtained the principal component (PCi) of ORI and COH images of the field of study. Then, based on the DSM (Figure 5b) and DTM (Figure 5c), the vegetation height image (Figure 6b) was obtained. This has great relevance in the process of separation of forest formations, because it is a direct measure of the vegetation height.



(a) (b) (c) (d)

*Figure 5 – (a) P-HH band image, (b) Digital Surface Model, (c) Digital Terrain Model and (d) forest height with slicing color from Barcelos/Brazil in the scale of 1:50,000.*

In addition to the vegetation height image, we obtained the images from the average (Figure 6a) and variance (Figure 6c) of the 1st principal component (PC1), which are used as input data for the extraction step of the classes of interest, through the applying the segmentation technique. In the Figure 6d it is shown the color composite images of the average and variance of PC1 and vegetation height, which were respectively associated with the channels of the red (R), blue (B) and green (G). From these three images, the steps of interactive segmentation RGB color composite were performed (Figure 7a), grouping (merge) interactive polygon generated (Figure 7b), depending on the super-segmentation obtained, and the final classification of the image. Based on the classified image, the exportation of the classes contour to vector files were carried out. This will compose the category of vegetation in the topographic maps (Figure 7c). In the Figure 7d other kind of cartographic product generated in this project is shown which the hydrographic and altimetric vector layers overlaid on a color SAR orthoimage.

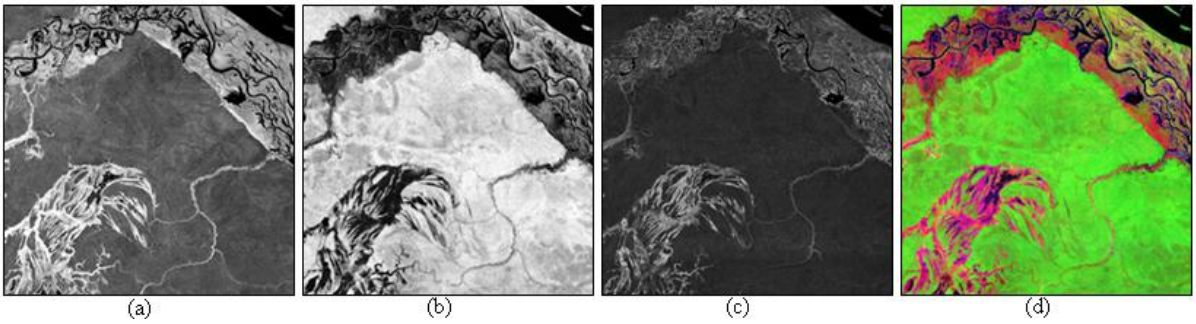



*Figure 6 - (a) Average of first principal component [R], (b) vegetation height - dh [G], (c) variance of first principal component [B] and (d) color composite [R][G][B] .*

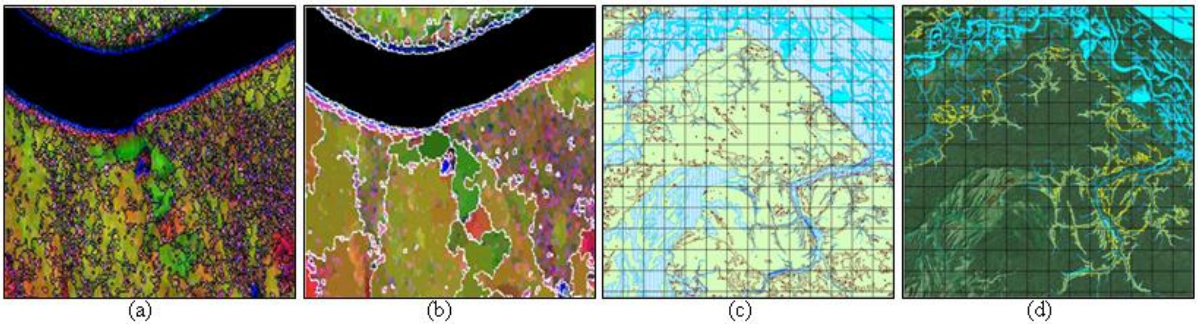



*Figure 7 – Interactive segmentation (a) before and (b) after adjustment of the attributes and (c) topographic map and (d) color SAR orthoimage with contour lines and drainage of Barcelos/Brazil at 1:50,000 scale.*

It is important to highlight the great potential for extraction of thematic information and cartographic features that can be explored from the use of techniques of visual interpretation and digital processing of various types of images that are acquired in the project "Amazon Radiography". The image shown in Figure 5d illustrates this potential, where the simple slicing of the image of vegetation height, with the combination of colors for different levels, allows obtaining the relevant information to the extraction of various forest formations.

### 5.4. Preliminary Assessment of Cartographic Products

Aiming to obtain the first classification of the input of the project according to the Standard Cartographic Accuracy, the field survey of three irregular grids of control points was performed, in forest and non-forest areas, for evaluation altimetric precision of the DTM. To this end, we calculated the differences between the elevations of the block extracted from the DTM 6364w0001s and field measurements for all points of these grids. The results are described in Table 3.

From the results presented in Table 3, we can conclude that the standard deviation values of the differences between the altitudes from the forest and non-forest areas, were lower than the standard error altimetric acceptable, that is 6.66 m, which corresponds to altimetric standard error of 1/3 from the equidistance between contour lines of 20 m, in the scale of 1:50,000 (Standard Cartographic Accuracy Altimetric for Class "A" maps). Therefore, based on the results, we can conclude that the DTM is compatible with the mapping scales of the project "Amazon Radiography" and these digital models can be employed to the production of cartographic documents on a scale of 1:25,000, with equidistance of 10 m between the contour lines and classified as Class “A” for altimetry.

*Table 3. Statistical parameters of the difference between the elevations extracted from the DTM and field measurements for the three irregular grids of control points.*

| Target | Number of Points | Minimum | Maximum | Average | Standard Deviation | RMS |
|---|---|---|---|---|---|---|
| Forest (1) | 948 | 0,0009 | 2,5777 | 0,9993 | 0,5715 | 1,151 |
| Non-Forest (2) | 336 | 0,0035 | 3,6672 | 1,2882 | 0,9172 | 1,5806 |
| (1) + (2) | 1284 | 0,0009 | 3,6672 | 1,0749 | 0,6906 | 1,2775 |

## 6. CONCLUSION

The airborne SAR and field support methodologies presented in this paper have been successfully used by DSG, which allowed up to the present time, the covering of an area equivalent to 85% of the areas of dense tropical forest to be imaged in the project.

Also, we presented in this paper the methodology for cartographic production, based on interferometric SAR images, in X and P bands, which is being used for obtaining large amounts of geospatial raster and vector data that compose the objectives of the project “Amazon Radiography”. Preliminary results obtained with the assessment of the Standard Cartographic Accuracy Altimetric for DTM showed the compatibility of this cartographic product with the mapping scales of the project present here and a possibility to use this digital model to generate maps in the scale of 1:25,000.

The Project “Amazon Radiography” has a strategic dimension and its combination with other subprojects will provide a deeper understanding of the Brazilian Amazon, through the most comprehensive collection of data on the Amazon, not obtained until now.

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