RESOURCES IN TROPICAL RAINFORESTS: FIRST RESULTS FROM TEST SITE ACRE, SW-AMAZONIA, BRAZIL

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Résumé
Dans le cadre d'un projet de coopération Canada/Brazil et avec le support financier de l'Agence spatiale européenne (ESA) et de l'Agence canadienne de développement international (ACDI), on a réalisé une campagne RAS-580 aéroporté au cours du mois d'avril 1992 en Amazonie brésilienne dans le but d'acquérir des données radar HH et VV en bande C.

Le but principal de l'expérience SAREX'92 est d'acquérir un ensemble de données radar en bande C, incluant des produits de simulation satellitaire, pour utilisation dans l'évaluation des données satellitaires RAS en bande C en milieu de forêt tropicale. Les résultats de ces travaux seront utilisés afin de réaliser un certain transfert de connaissances en "RAS" au sein des professionnels et des techniciens responsables de la gestion de la forêt tropicale au Brésil.

On présente ici les premiers résultats de l'évaluation des données RAS pour un site situé dans l'état d'Acre, au Brésil. On décrit l'utilisation d'images RAS corrigées géométriquement et radiométriquement et on fait le lien avec la détection des types de forêt, les pratiques liées à la déforestation en vigueur pour les pâturages et les petites agglomérations de même que les autres phénomènes anthropogéniques. On présente des exemples des différents traits du relief (dissection par drainage, érosion, topographie, etc.) détectés à partir des images RAS, et leur relation avec l'utilisation du sol et la gestion de l'utilisation du sol, lorsque possible.

Sur la base de l'interprétation, pour une zone couvrant 18 000 km², d'images à faisceau large traitées afin de bien reproduire la fidélité dont on s'attend des données de RADARSAT, il semble que les données RADARSAT présentent un potentiel énorme pour le suivi (monitoring) dans cette région. À partir de ces données, il est possible d'acquérir de l'information sur la déforestation tropicale, les réseaux de drainage, les sols et la végétation. Grâce à cette information, il est possible de gérer le développement afin de réduire l'ampleur des problèmes environnementaux qui ont caractérisé cette région par le passé.

Abstract
In the framework of a Canada/Brazil Cooperation Project and with the financial support of both the European Space Agency (ESA) and the Canada International Development Agency (CIDA), an airborne SAR-580 campaign to acquire C-band HH and VV radar data was undertaken during April 1992 in Brazilian Amazonia.

The overall objective of SAREX'92 is to acquire a C-band dataset, including simulated satellite data products, to be used for the evaluation of spaceborne C-band SAR data in tropical forest environments. Results of these investigations will be used to promote "SAR literacy" among professional and technical staff responsible for tropical forest management in Brazil.

This paper presents first results of SAR data evaluation from a test site in Acre, a State in Brazil. The use of geometrically and radiometrically corrected SAR images is described and related to the

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detection of forest types, deforestation practices for pasture and small settlements as well as other man-made features. Examples of different relief features (dissection by drainage, erosion, topography, etc), depicted from SAR images, and their relationships with landuse and landuse planning are shown when applicable.

Based on the interpretation of wide swath images, treated to represent data fidelity expected from RADARSAT, covering a total area of 18 000 km², it appears that the RADARSAT data has an important monitoring potential for this region. From the data, information on tropical deforestation, drainage networks, soils, and vegetation may be obtained. With such information, development may be managed, to avoid many of the severe environmental problems which have previously occurred in this region.

INTRODUCTION

Due to its size and physical diversity, Amazonia can be considered almost as a continent, with its own unique characteristics and problems. In the early 1970's, in order to have a first small-scale overview of its geology, geomorphology, soils, vegetation and potential landuse, the PROJETO RADAMBRASIL was created with the clearly defined objective of small-scale mapping based mostly on semi-controlled mosaics obtained by airborne SAR. Taking into account that it was the first systematic mapping (at a scale of 1:1 000000), it became the basis for many future and more detailed studies of this area. One of the major limitations of this huge mapping effort was the lack of detailed surface data (groundtruth) - probably due to logistical, time and funding constraints. Since then, to detect and map the natural resources of this extensive rainforest area, Brazilian federal and state agencies have relied heavily on optical remote sensing techniques to map the region, with particular interest in deforestation activities, flooding dynamics along the main rivers, and in local and regional geology.

Optical remote sensing in the tropics has limitations which are apparent when data is needed in a timely fashion. This is due mainly to the high moisture over all Amazonia, and consequently to high haze and cloud coverage. Furthermore, during the dry season, a frequent haze/smog cover from biomass burning inhibits the extensive use of data from optical sensors.

THE SAREX CAMPAIGN

Canada and Brazil share an interest in developing expertise on the analysis/evaluation of SAR data in the tropics. As one step in preparation for RADARSAT (Raney et al. 1991), the SAREX'92 (South America Radar Experiment) was established. The Brazilian part of SAREX'92 is a cooperative research project, and is funded by the European Space Agency (ESA), the Canadian International Development Agency (CIDA), the Brazilian Institute for Space Research (INPE), the Brazilian National Council for Scientific and Technological Development (CNPq) and CCRS.

The Brazilian - Canadian cooperative effort has two primary objectives: 1) to obtain a C-band data set with the Canadian SAR-580 in order to evaluate the capabilities of C-band SAR to detect and map land features such as forest types, clearings, burned areas, regeneration areas, flooding, mapping of artificial lakes (i.e. water reservoirs of hydroelectric power plants), and to simulate RADARSAT images from these data; 2) to promote "SAR literacy" among professionals in the area of planning and environmental/tropical resources management both in Brazil and Latin America. The project includes joint efforts between CCRS and INPE specialists in organizing workshops and performing SAR data interpretation training courses for remote sensing specialists within Amazonia.

TESTSITE ACRE: OVERALL DESCRIPTION

The State of Acre is located in the southwest of Amazonia and has approximately 95% of its surface covered by the original tropical rainforest. Its soils are mostly poorly-consolidated Cenozoic sediments. As a result, the area presents a rolling relief with low hills which are remnants of a former plateau, approximately 100 m above the average terrain level. The plateau is strongly dissected at its edges. The drainage erodes deeply in the sedimentary layers, showing well defined floodplains with meanders as well as rivers carrying sediments. The soils are normally deeply
weathered, and due to their chemical composition, are easily erodible. Due to this, the terrain presents problems for road construction and other civil engineering projects.

The economy of Acre is based primarily on extraction of latex from *Hevea Brasiliensis*, for rubber production, collection of Brazil nuts and timber from tropical hardwoods. Over the last two decades, due to the governmental land occupation policy then in place for Amazonia, deforestation rates increased quickly. Large areas were cleared for cattle ranches ("fazendas") and settlement projects. One of these, the "PAD Humaitá", located at the north of the Acre State capital, Rio Branco, is easily recognized by its special geometry: eight roads radiate at 45 degree angles from a central square, which is the probable birthplace of a future town. Along these roads, the lots are typically 50-100 ha in size.

Rubber tapping is an economic activity that is well adapted to the local tropical environment. The rubber tappers deforest very small sections of land, the so-called "colocações", to plant annual crops for their own use. This type of land occupation, known as "slash and burn", "shifting cultivation", or "swidden" is sustainable when applied in a small scale. It has been used over many centuries by the aboriginals, and has not caused any major damage to the rainforest, since the small deforested sections are abandoned after a few years of agricultural use. Tropical rainforest then gradually recovers these small areas again. The "colocações", usually a few hectares in size, can often be recognized on the airborne C-band SAR scenes. They are more frequent to the south of Rio Branco, which is an old rubber extraction area.

There is a strong commitment of the government of Acre to protect its forests resource, especially the "Protected reserves for extraction". As a consequence, our cooperating agency in Acre State, Fundação de Tecnologia do Estado do Acre (FUNTAC), generates an annual map of the increment of deforested areas, using primarily data from the Thematic Mapper supplied by INPE. FUNTAC is actively engaged in evaluating SAR data for the same applications.

**DATA ACQUISITION**

SAR data were obtained with the CCRS C-SAR sensor (Livingstone et al. 1988) in the three characteristic operating modes of the SAR-580; nadir, narrow swath and wide swath:
- nadir mode: 20km swath, incidence angles of nominally 0 to 74 degrees with 6 x 6 m resolution,
- narrow swath mode: 18km swath, incidence angles 45 to 76 degrees with 6 x 6 m resolution,
- wide swath mode: 60km swath, incidence angles 45 to 85 degrees with 10 x 20 m resolution.

The SAR data were processed in real time on-board. Photographic negatives were generated at CCRS using the AIR-2 airborne image production system. Most of the interpretations reported in this paper were made from prints made from these negatives. For some sections of the area under study, the data were enhanced using digital processing to remove residual antenna pattern effects and geometric distortions, and to provide a contrast stretch optimized for the area of interest.

Field verification data also were collected during the week of the radar data acquisition mission. Extensive 35mm photographs were made to document conditions at the time of the radar mission, based on two flights in a Cessna 172 aircraft over the study areas, and ground visits to sites of particular interest. Quicklook data from the C-SAR real time processor were used to plan field verification data acquisition.

**SAREX IMAGE ANALYSIS**

An area of approximately 33,000 km² was imaged during the SAREX campaign at Acre alone. A selection was made of some scenes that present characteristic relief and vegetation features of the region under study. Data analysis was performed using a PROCOM-2 image enlargement equipment, as well as through visual interpretation of prints enlarged from the original negatives. In this paper we describe those features which have been mapped through visual interpretation of the entire data sets of two wide swath flightlines, enlarged to prints at 1: 100 000 scale.
The Rio Purús, the largest river of Acre State, flows within a floodplain, in SW-NE direction. It has created two very well defined river terrace levels. The lower terrace, approximately 5 to 10m high, is characterized by several fluvial features such as oxbow lakes and meander scars which are frequently covered by vegetation (Fig.1). This area also shows most of the man made features such as large cleared areas that are used primarily for pasture and/or agriculture. The larger tributaries of Rio Purús also show well-defined floodplains, such as the Rio Iaco, Córrego do Ouro, Rio Antimarã and Riozinho do Andirá. The upper terrace of the Purús is a section located between the lower terrace and the foothills of a former plateau that has been strongly dissected to hills of different heights and sizes.

The remnants of this former plateau are readily visible on the SAR image (Fig. 1). This plateau apparently dips a few degrees to NE, according to the main drainage direction. This drainage is well depicted on SAR images, due to strong erosion of the main and secondary channels. The differences in texture, and the bright return of those slopes turned towards the radar illumination, permit a clear definition of a scarp around the whole plateau remnant.

Within the area where this plateau is most dissected, only the main river channels appear relatively clear, whereas secondary channels are difficult to plot precisely. Here the image texture allows only an initial division of the main relief units. This observation is also valid for the section between Rio Purús and Rio Acre, where, due to intensive relief dissection, only the main relief units, as well as the main floodplains, can be clearly defined.

Along the route Rio Branco-Sena Madureira (BR-364), the larger deforested sections, frequently rectangular, are cattle ranches of several hundred to thousands of hectares. The principal purpose of site selection at these huge deforested sections, which were afterwards replanted with pasture, seems to be closeness to the main road, in order to guarantee transportation facilities for the cattle. Closer to Rio Branco, Acre’s State Capital, the deforestation pattern is mixed: larger rectangular sections indicate clearings for cattle ranches, whereas the smaller deforested areas indicate agricultural land use. To the north of Rio Branco a large agricultural settlement project (PAD-Projeto de Assentamento Dirigido) Humaitá is well depicted from the SAR image.

Deforestation has become a major problem in Acre. Due to the high activity clays ("argil ses gonflantes") in the soils from this region, any direct exposure of bare soils to rain starts an intensive erosion on slopes and silting of rivers. One result of this is sediment overload in the river channels.

PRELIMINARY INTERPRETATION OF WIDE SWATH C-HH SCENES, REGION RIO BRANCO-XAPURI

This region is drained by Rio Acre and tributaries such as Rio do Rola and Rio Xapuri. The drainage network generally is portrayed in the SAR imagery with high contrast. Several relief/landscape features are clearly evident in the wide swath scenes. Both the floodplain and an upper level of river terraces can be depicted from the images. Above these river terraces, at the eastern margin of Rio Acre, the floodplain is bordered by an area of rolling relief with hills that become almost flat in the area close to the Rio Branco-Xapuri road (Brasil, 1990). The western margin of Rio Acre is bordered by an escarpment, that is well perceived throughout a lengthy river section. To the south of the town Xapuri (birthplace of the rubber tapper Chico Mendes) the floodplain of Rio Acre also is clearly depicted. The Rio Xapuri has a relatively large floodplain for its size. The large floodplains of all major rivers found in Acre State as well as the meandering character of all large collectors, indicate that they were formed under climatic conditions that were more favourable to erosion/deposition than the present conditions. This can be associated with one of the interglacial periods of the Quaternary, when different regions within the tropics suffered under very aggressive wet climates.

The drainage network in the radar image can be grouped into several different classes, depending on its density. From this, inferences can be made about the relief, about the erosion properties of the
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soils, and possibly also about the substrata (rocks). Areas of higher stream density have strongly
dissected relief of hills of different sizes that indicates more easily eroded soils, while areas of lower
stream density are flatter and probably indicate more erosion resistant soils and rocks.

The tropical lowland rainforest, the original vegetation cover, has been cleared extensively along the
road Rio Branco-Senador Guiomard-Xapuri-Brasiléia, primarily for the establishment of cattle
ranches. The large rectangular deforested sections are very well seen on wide-swath SAR scenes.
The interpretation of deforested areas is based on the very smooth texture of deforested land
compared to the coarser texture of the primary rainforest canopies. When the radar illumination is
favourable for each clearing, there also is a shadow along the near edge and a bright return from the
far edge, which helps to delineate the boundary of the deforested section.

Cattle ranches often have different types of land cover that can be depicted from the SAR image,
such as bare land with low grass vegetation, areas of vegetation regrowth (known as "Capoeira"),
planted grasslands ("Brachiaria"), and the regeneration of vegetation that naturally invades areas of
planted pasture (Fig. 2). Individual "Castanheiras", the Brazil-nut trees, can be seen on the higher
resolution narrow swath images because of the radar shadow cast on the grassland from the crown
and stem.

In contrast to the deforestation for cattle ranching activities, the "colocações" are very small
deforested sections, with an area of approximately 5-20 ha or even smaller. These small clearings,
dispersed within the rainforest, are more concentrated around the town of Xapuri, since this is an
old area of latex extraction. Another area of concentration of "colocações" may be found in the
Extractive Reserve to the south of the Sugar-cane plantation of ALCOBRA.

PRINCIPAL CONTRIBUTIONS OF SAR DATA FOR NATURAL
RESOURCES EVALUATION WITHIN THE AREA UNDER STUDY

In Acre, fairly detailed mapping of the floodplains can be performed, with special emphasis on
former meanders (oxbow-lakes) and abandoned riverbeds. This is important, among other reasons,
to understand the dynamics of annual flooding, an essential information for planning development
such as location of roads and settlement projects. It should be noted that oxbow-lakes are
particularly important in the tropics for fish reproduction, which provides a natural source of protein
basis for consumption by both humans and fauna.

Accurate mapping of the drainage system and estimation of the soil erosion potential, are among the
main contributions of SAR for the natural resources evaluation of this region. Estimation of soil
moisture within deforested areas is of interest, in order to quantify the influence of large scale
deforestation on both runoff and evaporation rates within the water cycle of the region. This
application of SAR imagery is under investigation.

Location and analysis of clearcut areas within the rainforest is one of the main contributions of SAR
data in this region. Results show success in the detection of large (100's to 1000's of hectares)
clearings for cattle ranches, medium sized (50 - 100 ha) clearings for farms, and at least the larger of
the small clearings (above approximately 20 ha) of the rubber tappers "colocações". An additional
contribution would be the analysis of regeneration patterns of the original vegetation, particularly on
those areas of former cattle ranching, an application that also is under investigation.
CONCLUSIONS

Wide swath C-band radar data set has been acquired over an area of the Amazon rainforest in the State of Acre, Brazil. This region contains large areas of primary rainforest, as well as deforestation for cattle ranches, agricultural settlements, and shifting cultivation. The data interpreted were similar in quality and spatial resolution to images expected to be received from the RADARSAT satellite. A geomorphological interpretation showed the value of such imagery in depicting drainage networks, floodplains, abandoned meanders, and general topographic features. Areas deforested for cattle ranches and farms were clearly visible because of their smooth texture, which contrasted sharply with the rough texture of the primary forest canopy, as well as the distinct rectangular patterns typical of such development projects. Rubber tappers' clearings larger than about 20 ha were also readily detected. SAR data is expected to play a major role in monitoring tropical deforestation. Early results are promising for the detection/mapping of drainage networks, soils, vegetation cover and regrowth patterns in the typical conditions found in Acre. The Acre SAR dataset is being used for more extensive analysis both at CCRS and at INPE.

REFERENCES


FIG. 1
C-HH Wide Swath Section of Rio Purus
P = Plateau
LT = Lower Terrace
UT = Upper Terrace
H = Hills
D = Defrosted Sections

FIG. 2
"FAZENDA" at C-HH Narrow Swath Section of Rio Acre, South of Rio Branco
F = Primary Forest
G = Grassland
O = Overgrown Grassland ("Capoeira")
C = "Colocaçoes"