FOREWORD

The Japanese Earth Resources Satellite-1 (JERS-1) carrying two high-resolution optical and microwave imagers terminated on October 12 1998. It was estimated that the temporal degradation of the solar power generator caused the short circuit. During six and a half year life, it collected 70,000 SAR images and 40,000 OPS images over the land. Although the loss of the satellite is a pity, these huge amount of data are the treasures to the wide range of the researchers.

Many studies were conducted within the JERS-1 verification program (a first stage JERS-1 research program). Their scientific results and the effectiveness of sensor were shown at the intermediate and final result reporting meeting, 1993 and 1994, respectively. As a follow-on activity, NASDA has conducted the internal and PI-based researches since 1995, both of which focused on SAR interferometry and SAR based forest monitoring as well as the other themes. The total 29 (20 for forest monitoring and 9 for SAR interferometry) PIs are involved in the PI-based program. The research report has appeared as here stand. Because that 1) the researches were conducted based on JERS-1 verification program, 2) data provision limitation was relaxed so much than the previous, more quantitative results have been obtained.

As a results of this fruitful research activities, our understanding of SAR calibration/validation issues has significantly progressed. I believe this concise scientific reports may stimulate your research minds and help your future scientific activities.

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The use of JERS-1 images in CIAT's benchmark sites in Puerto López, Colombia, and Pucallpa, Peru

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Abstract

This report presents ongoing work using JERS-1 for land use studies and planing in CIAT's benchmark sites in Puerto López, Colombia, and Pucallpa, Perú. We have used the high-resolution images to map gaps in the gallery fores and to fill in missing portions of the forest map derived from a Landsat TM image affected by a cloud haze. We are also using it to refine a classification conducted with Landsat TM images by resolving the ambiguity between healthy improved pastures and shrubby vegetation. In the Pucallpa study site, the imagery has been used to map flooded areas for agricultural planning. In addition to this, we will be continuing our analysis of the multitemporal image series of this site, to determine the best techniques to identify recently cut forests and regrowth, in collaboration with other GRFM investigators. The Amazon mosaic is beginning to be used by local and regional authorities in the Colombian Orinoco region for land use planning.

1-Introduction

The International Center for Tropical Agriculture (CIAT)'s mission is to contribute to the eradication of poverty in tropical countries through the application of science to the development of technology. In that context, it is working at the development and conservation of genetic as well as natural resources. It's Natural Resources program has an eco-regional focus, and it works in three major eco-regions: savannas, forest margins and hillsides. Through the development and testing of agricultural and other land use options in specific benchmark sites, it aims at developing knowledge and guidelines that can be applied elsewhere in these eco-regions. The project entitled "Land use dynamics and sustainability", of which the authors are part, aims at supporting policy decisions and land use planning. One of the components of this is to develop GIS-based decision support tools.

The objectives of our involvement in the Global RainForest Monitoring (GRFM) project are to use JERS-1 as a source of data on land use in our study sites, to provide examples of applications that can be conducted by land use planners in other tropical areas, and to develop simple methods that allow us to use the images for the desired purposes. Much of the work presented here is in the applications rather than the research domain. Nonetheless, we had two important research questions, which were a) to evaluate if and how can JERS-1 images help fill gaps in the classifications of partly cloud-covered optical imagery b) to evaluate if and how can JERS-1 images can help resolve ambiguities found between certain classes in Landsat TM imagery.

2-Methods and research activities

This report presents the research and applications we are conducting using JERS-1 SAR images, alone and in conjunction with other images, to map land use in CIAT's benchmark sites. The benchmark site used for the savannas eco-region comprises the Puerto López municipality, Colombia, and the site for the forest margins eco-region is located near and around the town of Pucallpa, Peru. The locations of both sites are shown in **figure 1**. The benchmark sites used for the hillsides research are located in Central America and are not covered by this study. We also present the beginning work related to the use of the Amazon mosaic for land use planing the Orinoco and Amazonian regions of Colombia.

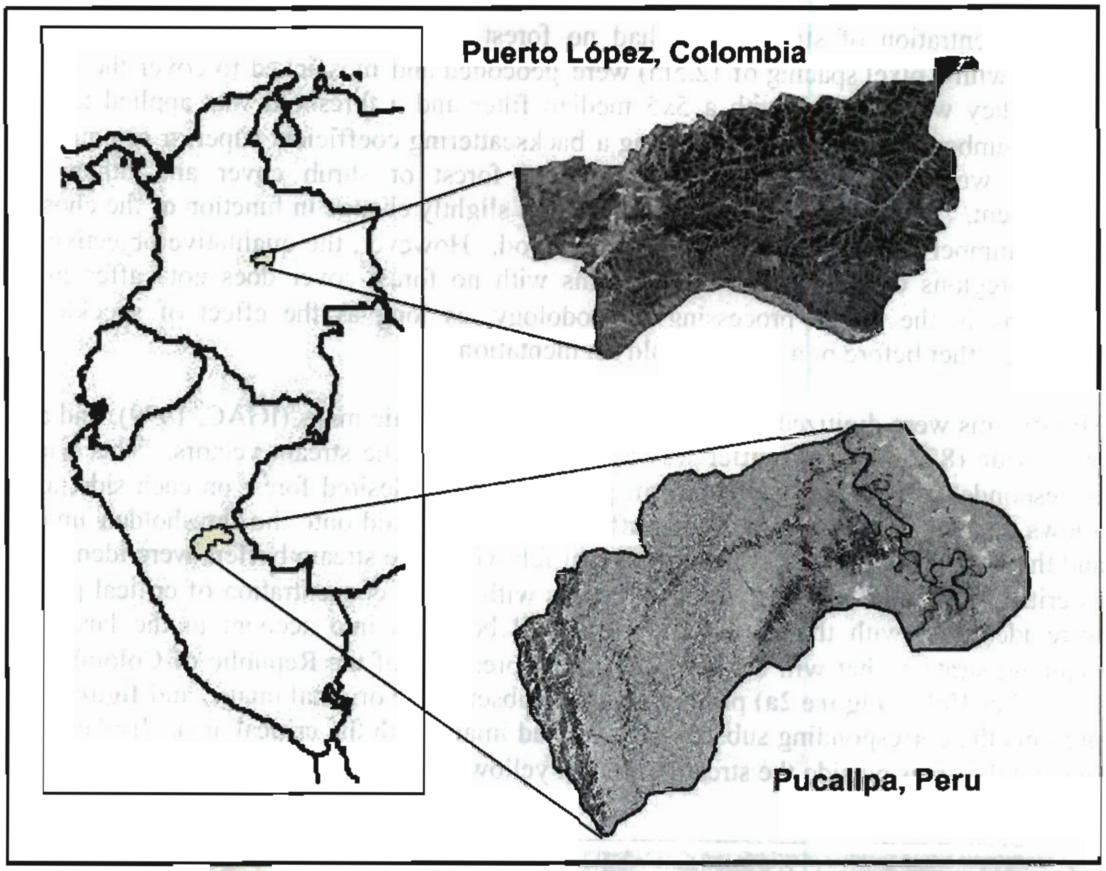

Figure 1: location of the Puerto López and Pucallpa benchmark sites

3-Problems, development and preliminary results

This section will be divided in three sub-sections, relating the specific problems of each site. In sub-sections 3-1 and 3-2, we will respectively present the studies conducted in Puerto López and Pucallpa with high resolution images, and in section 3-3, the use of the mosaic for land use planning. Each sub-section involves different methods for image processing.

3.1 Studies in the Puerto López municipality

3.1.1 Mapping of gaps in the gallery forest

The Colombian law stipulates that 30m of natural vegetation must be preserved on either side of streams (INDERENA, 1978). In the savannas of the Colombian Eastern Plains (*llanos orientales*), which are in great proportion grasslands, the narrow strips of forest along the streams play a very important role. The gallery forest stabilizes stream banks and acts as buffers for water contamination, forms biological corridors and is a reservoir for biodiversity. Using JERS-1 images, we wanted to establish areas where there was a high concentration of streams that had no forest on their banks. Four full-resolution images (with a pixel spacing of 12.5m) were geocoded and mosaicked to cover the study area. They were filtered with a 5x5 median filter and a threshold was applied to the digital number. Pixels with a presenting a backscattering coefficient superior or equal to −10 dB were classified as having sufficient forest or shrub cover and others as insufficient. The resulting surfaces in each class slightly change in function of the chosen digital number threshold and the filtering method. However, the qualitative objective of finding regions of concentration of streams with no forest cover does not suffer from variations in the image processing methodology, as long as the effect of speckle is reduced, either before or after threshold segmentation.

The streams were digitized from 1:25 000 scale topographic maps (IGAC, 1979), and a 7 pixel wide (87.5m) study buffer was established around the stream vectors. This width corresponds to the width of the stream plus the 30m of desired forest on each side, and allows a small security factor. The buffer area was overlaid onto the thresholded image and the areas of insufficient forest cover that fell within the stream buffers were identified as critical areas and mapped in red. Regions with a high concentration of critical pixels were identified with the municipality and will be taken into account in the land use planning strategy that will be presented to the president of the Republic of Colombia in December 1999. **Figure 2a)** presents a small subset of the original image, and **figure 2b)** presents the corresponding subset of the filtered image with the critical areas displayed in red and the areas outside the stream buffer in yellow.

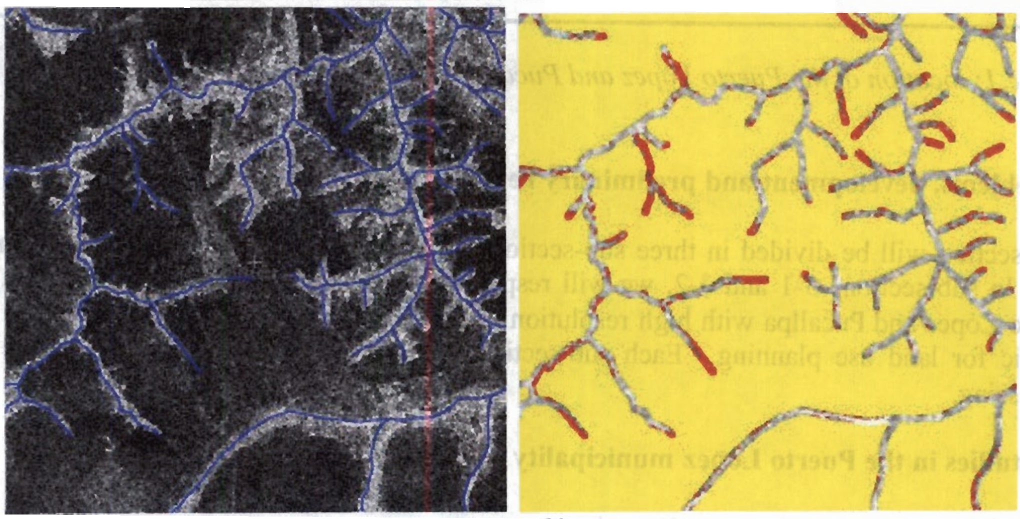

Figure 2: a) 6.4 km × 6.4 km subset of the original JERS-1 SAR image. b) corresponding subset of the filtered image with the critical areas displayed in red and the areas outside the stream buffer in yellow

3.1.2-Helping solve ambiguities in land use determination with Landsat TM images

The previous section presented an assessment of the gallery forest "deficiencies" made with JERS-1 alone. We then proceeded to the evaluation of land use changes using Landsat TM imagery acquired in January1988 and in January1996, based on land use samples that were identified in the field in 1996. The objective of that component of the study was to determine the areas that were converted from natural pasture (or "native savanna") to introduced (or cultivated) pastures, and to determine changes in the extent of the gallery forests. We experimented two types of problems while conducting this study with Landsat TM images: a significant part of the 1996 image was affected by a diffuse haze cloud that greatly affected the classification. Beneath the haze cloud, many stretches of forest were classified as other uses, which falsified our assessment of forest changes. Also, in areas not affected by clouds we obtained a certain degree of confusion between improved pastures and transitional vegetation (extensions of shrubby pasture). In deed, 21% of the pixels in our introduced pastures verification sites were classified as scrubland vegetation. We thought we could use the 1996 JERS-1 SAR images to complement the 1996 Landsat TM, and obtain a more precise land use map.

For this stage of the study, the full resolution, geocoded but unfiltered JERS-1 power images mentioned in the previous section were resampled to 25m pixels using 2x2 block-averaging. They were overlaid with the Landsat TM images, which were also geocoded and resampled to a 25m pixel spacing. The training areas were used to extract statistics on the JERS-1 SAR backscatter for the different land uses being mapped. **Figure 3** shows the ranges of backscattering coefficient corresponding to the mean power ± one standard deviation.

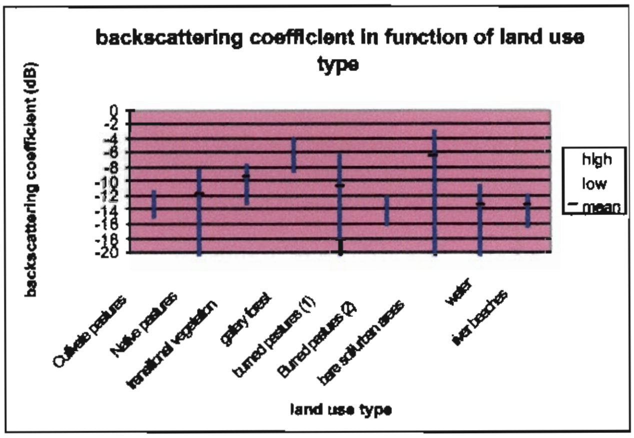

Figure 3: ranges of backscattering coefficient corresponding to the mean power ± one standard deviation on the 21-03-96 JERS-1 SAR image.

One can see that there is significant overlap between the classes, but we established the following ranges for the following three classes: $\sigma° < -11$dB for "short vegetation or water", -11 dB$<\sigma°<$ –8dB for "scrubland" (or transitional vegetation) and $\sigma° > -8$dB for "forest or urban areas". These ranges correspond relatively well to the values published by Luckman and Baker, who, in their study of Amazonian forest, used a lower threshold of –10.7 dB for young regrowth and of –8.3 dB for old regeneration and primary forest. We then derived a map of our three classes from the JERS-1 SAR by thresholding the power images according to the corresponding backscatter ranges. The resulting thematic images were then filtered to remove all isolated groups of three pixels or less.

Using the 1996 JERS-1 SAR and the 1988 Landsat TM classifications, the 1996 TM image classification is being corrected in the following manner:

- If a pixel was classified as forest from the 1988 image and as forest in the JERS-SAR image, then that pixel remains forest no matter what it was classified as from the 1996 TM.
- If a pixel is classified as introduced pasture in 1996 TM image but is classified as "scrubland" in the JERS-1 SAR image, then it is scrubland.
- Conversely, if a pixel is classified as scrubland in the 1996 TM image and as "pasture or water" in the JERS-1 SAR image, then the pixels are ambiguous. An operator must determine if they correspond to introduced or to native pastures, through visual interpretation, taking into account the nature of the surrounding pixels.

The number of introduced pastures pixels in our training sites that were classified as scrubland diminished from 21% to 1.7% through this process.

Figure 4 a) shows Image subsets of the Landsat TM, 09-01-1996, assignment of bands 4, 5 and 3 in the Red, Green and Blue display channels. Figure 4 b) shows the same portion of the 21-03-96 JERS-1 SAR and figure 4c) shows the JERS-1SAR with the areas segmented as scrubland in green. The yellow lines on frames a) and b) correspond to training sites; the ones on top correspond to improved pastures, and the one towards the right of the subset, to gallery forest.

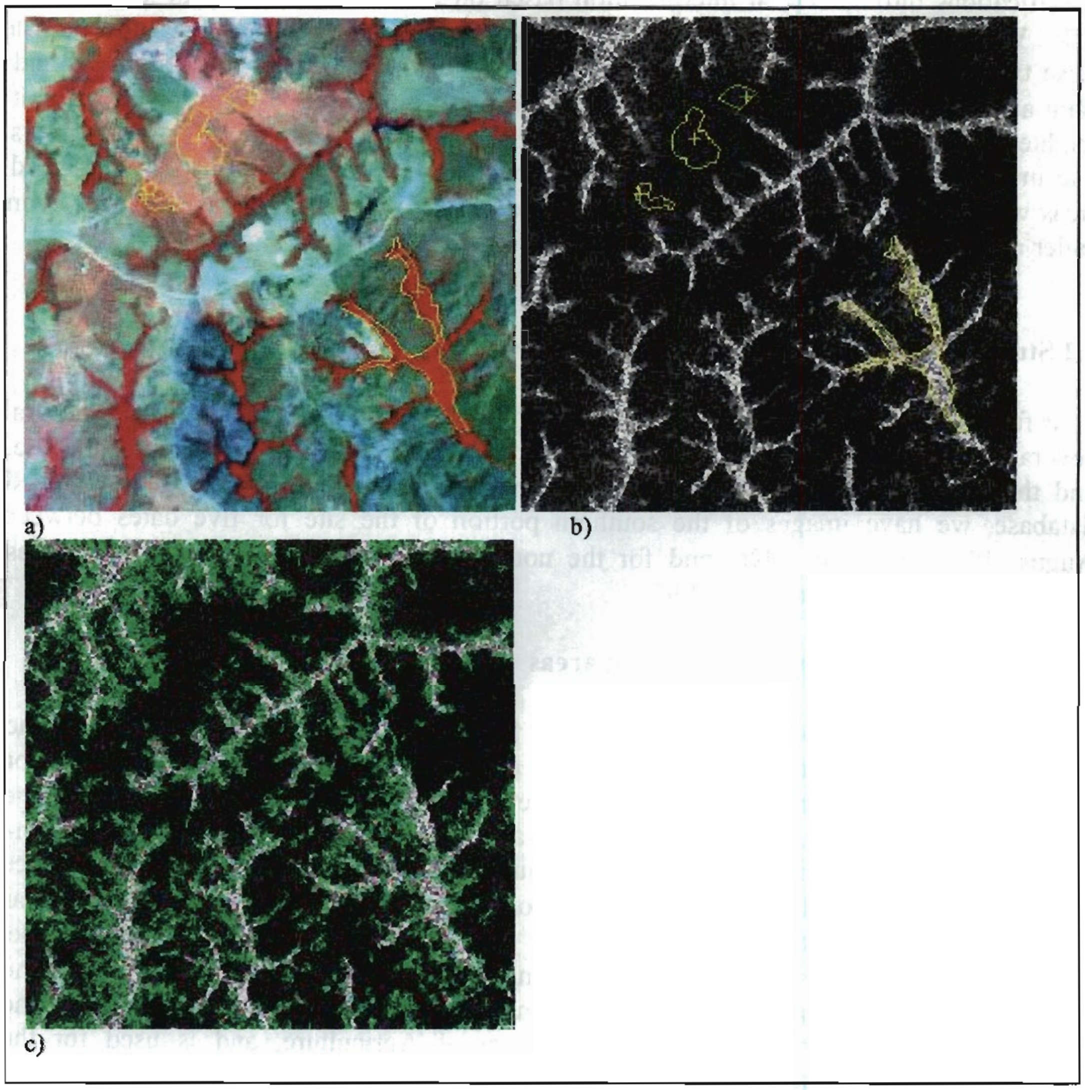

Figure 4: Image subsets (6.25 km × 6.25 km) in the Puerto López municipality. a) Landsat TM, 09-01-1996, assignment of bands 4, 5 and 3 in the Red, Green and Blue display channels. B) JERS-1 SAR of 21-03-96 c) JERS-1SAR with the areas segmented as scrubland in green

The use of the 1996 JERS-1 SAR image has allowed us to map forests and scrubland in the areas affected by clouds in the 1996 TM image. However, the distinction between introduced pastures, native pastures and bare/degraded soils remains impossible in this area. We are hoping to acquire a cloud-free Landsat TM image at the beginning of 1999 in order to be able to establish rates of change from native to introduced pastures for the Puerto López municipality. We must say that even with cloud-free optical images, there remains a degree of confusion between native and introduced pastures, because of the various levels of grazing and degradation of the introduced pastures, and the various regrowth stages of the native pastures after burning. This can be reduced by editing the classifications through visual interpretation based on field observations, but is a tedious task. We are presently studying Radarsat images, hoping they will help us distinguish these two general types of pasture. A combination of the effects of soil roughness and plant architecture could be responsible for the fact that improved pastures tend to exhibit brighter backscatter in C-band than do native pastures (Beaulieu *et al.*, 1998). This is true in the areas with flat to slightly rolling topography, but not in the heavily dissected areas where relief and the high roughness of the stony soils cause high backscatter even under native pastures.

3.2 Studies in the Pucallpa benchmark site, Peru.

Four full-resolution JERS-1 scenes are necessary to fully cover this site. A multitemporal coverage was provided by NASDA for two of these scenes, which cover most of the site, and the remaining area was covered by images of June 1996. In our georeferenced database, we have images of the southern portion of the site for five dates between August 1994 and June 1996, and for the northern portion of the site for eight dates between august 1994 and April 1997.

3.2.1 Mapping of the extent of flooded areas

The image acquired February 9th, 1996, shows the highest extension of flooding along the Ucayali and Aguaytía rivers, as can be seen on **figure 5** The microwave radiation emitted JERS-1's L-band SAR partially penetrates the forest canopy and reaches the flooded ground surface. The flooded forest appears noticeably brighter than the non-flooded forest because it produces double bounces of the radiation on the water surface and tree trunks. This flooding is impossible to map from electro-optical images such as from the SPOT and Landsat satellite, because it is hidden by the canopy. The blue line, delineating the extension of flooding, has been digitized from visual interpretation of the image. A map showing the radar image and flooding extent has been given to the Pucallpa local office of the Peruvian Ministery of Agriculture, and is used for the planning of crops to promote with farmers. Some crops such as Camu camu grow very well in flooded environments.

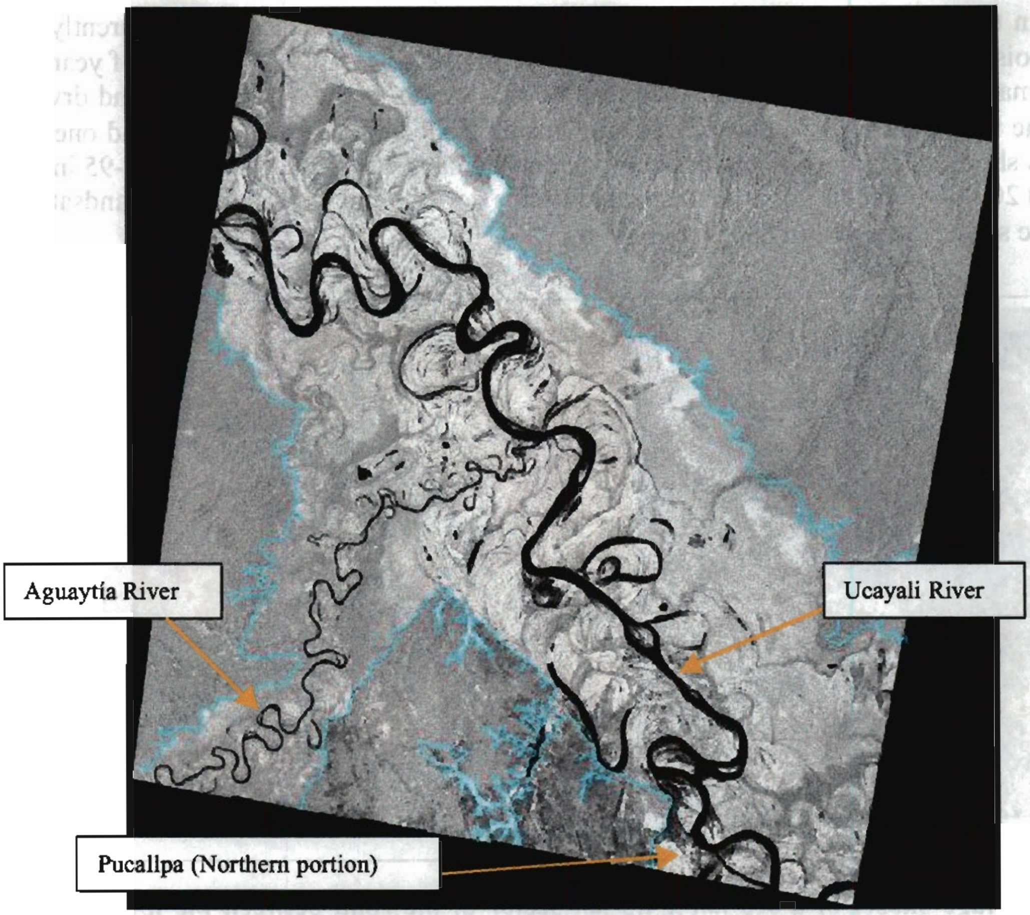

Figure 5: JERS-1 SAR full-scene image of the Ucayali river, North of Pucallpa at high water (February 9th, 1996). Bright tones indicate flooded vegetation. Flooding extent is indicated by the light blue line.

3.2.2 Study of changes in forest and agricultural areas using multitemporal image series

We are only beginning this stage of the study, therefore we are not yet presenting results in this section. For the moment, we have geocoded the images of the different dates in order to overlay them, to choose the most appropriate date combinations, and to choose sites for conducting field work. Once the history of a sufficient number of fields is determined through interviews, we will proceed to a quantitative analysis of the backscattering variations in time. The backscattering power of the images has been calculated from the digital number for the full resolution images. The resulting power images have been resampled to a pixel spacing of 25m using 2x2 block-averaging. These images were geocoded and displayed in different combinations in order for us to choose the sites.

When these images are combined in a color composite, very intense color changes appear because of changes in the water level and moisture conditions. In order to be able to see changes in the forest/agriculture contact areas, we must compare images with apparently similar moisture conditions. These don't seem to be predictable based on the time of year that the images were acquired, since there can be rain events in the dryer season and dry days in the rainy season. We chose three sites for the collection of ground data, and one of them is shown in **figure 6** as a color combination of dates 30-08-94 in red, 13-11-95 in green and 20-06-96 in blue. It is accompanied by the corresponding portion of a Landsat TM image subset, acquired in September 1996.

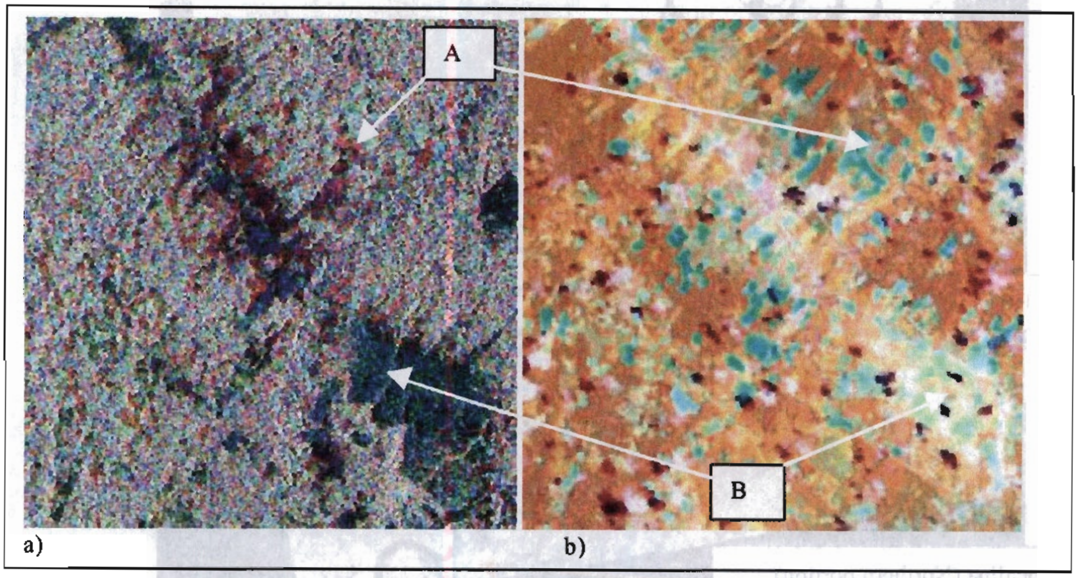

Figure 6: Image subset of a 7.3 km x 7.3 km sector of the road between the towns of Neshuya and Curimaná. a) JERS-1 SAR multi-temporal composition, 30-08-94 in red, 13-11-95 in green and 20-06-96 in blue. b) color-composite Landsat TM image of 22-09-96, bands 4, 5, 3 in red, green and blue.

In figure 6, the arrows marked with "A" indicate more recent clearing with a red coloring around the dark previously cleared areas, caused by higher backscatter in the 1994 image. The ones marked with "B" indicate a young oil palm plantation, presenting a blueish color in the radar composite caused by a higher backscatter in the 1996 image.

The objective of the work planned for 1999 is to determine the best image processing techniques to map recently cut forest and regrowth areas. We also want to determine the degree of possible confusion that could exist between regrowth and crops such as corn that can produce relatively high backscatter. We hope to conduct this work in collaboration with other GRFM investigators, in order to test techniques developed at INPE and JPL, including texture and wavelet transforms. This methodological exercise would be conducted using the original images, before geocoding and averaging, to avoid the effects of resampling on image texture.

3.3 Use of the amazon mosaic for land use planning in the municipalities of the Colombian Orinoco and Amazon regions

The Colombian portion of the mosaic has been integrated in user-friendly GIS packages and will be used by for land use planning at the municipal, departmental and regional levels in the Orinoco. Various institutions in the Orinoco region are in the process of forming a network of GIS users interested in the planning of sustainable development of the region. These institutions include CORPOICA, CORPES-Orinoquia, Corporinoquia, corpomacarena, CIAT, and the planning offices of some of the departmental governments. This association will provide technical assistance and data to the municipalities, which must turn in their land use strategy by December 1999.

CIAT has begun the development of a GIS-based decision support system that will guide users through the processes of land use planning and agricultural opportunity search. We are now working with the programs Mapmaker (Duddley, 1999) and SPRING (INPE). Mapmaker is a user-friendly GIS, with a basic version that can be distributed free of charge. Satellite image compositions can be imported in the TIFF or BMP format to be used for visual interpretation, but the program has no image processing capacities. SPRING, developed by INPE in Brazil, has full image processing capacities and is also available through the internet. **Figure 7** shows the mosaic in a MapMaker database for the department of Meta, which also contains socioeconomic and agricultural production data. For the moment, the image is simply visualized as a background to the vectorial data; it shows rivers and drainage, types of landscapes and location of forest and savanna areas, as well as many large-scale vegetation features, as described in Hess *et al.*, (1998). It will soon be used for the mapping of landscape types based on visual interpretation. The mosaic completely covers 5 of the 7 departments forming the Orinoco region, and it is now the most appropriate available source of image data at a regional scale, for these purposes. Since the mosaic completely covers the Colombian amazon region, we will also be making it available to the planning agencies in this area.

We must mention that in order to overlay it with other information, we had to further geocode the mosaic. In the Puerto López area, where we have accurate vectorial coverages of streams, the mosaic had to be shifted by some 2km in X and 1 km in Y.

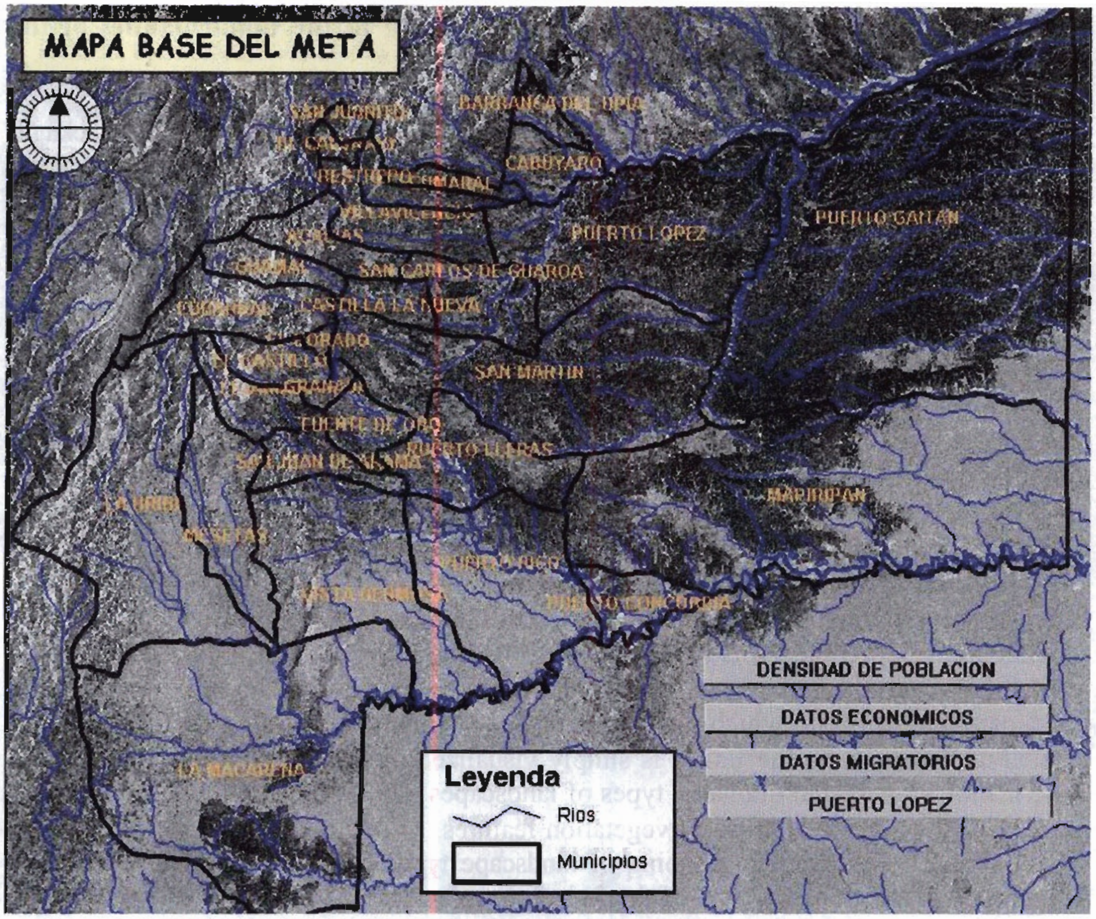

Figure 7: front page of the preliminary version of our GIS-based Decision-support tool for the department of Meta, in the MapMaker software. Buttons on the lower left allow access to other maps. Technical libraries will guide the users through the processes of participatory rural diagnosis, agricultural product opportunity identification and land use planning.

4- Conclusions

In the studies described in this report, we have shown many uses of the JERS-1 SAR images in savanna and forests, both in the full-resolution and mosaic formats. We have used the high-resolution images

- To map gaps in the gallery forests in the Puerto López study area
- to fill in missing portions in the forest map derived from a Landsat TM image affected by a haze cloud,
- to refine a classification conducted with Landsat TM images, by resolving the ambiguity between healthy improved pastures and shrubby vegetation
- to map flooded areas for agricultural planning in Pucallpa

In addition to this, we will be continuing our analysis of the multitemporal image series of Pucallpa to determine the best techniques to identify recently cut forests and regrowth, in collaboration with other GRFM investigators.

The Amazon mosaic is beginning to be used by local and regional authorities in the Colombian Orinoco region for land use planning.

5-Acknowledgements

We would like to give special thanks to NASDA and RESTEC who have provided all the images for this study, as well as all the people who have made the GRFM project possible. We would like to thank Ahmed Allam who conducted the classifications of the 1988 and 1996 Landsat TM images of the Puerto López area while on training at CIAT, and Pablo Imbach, Ovidio Muñoz and Maryory Rodriguez, who are working with the decision support system shown in figure 7. We also thank Euan Crawford who conducted field work in the Puerto López site in 1996.

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