esa SP-405
February 1997
ISBN 92-9092-303-2

International Seminar
Seminario Internacional

The Use and Applications of ERS in Latin America

Uso y Applicaciones de ERS en América Latina

Vina del Mar, Chile
25-29 November 1996

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INVESTIGATION OF DEFORESTATION DYNAMICS AND LAND USE CHANGES BY ERS–1 SAR DATA IN RONDONIA, BRAZIL

Michael Schmidt[1], Manfred Keil[1], Dominic R. Scales[1], J.R. Dos Santos[2], H. Kux[2]

[1] *German Aerospace Research Establishment (DLR), D–82234 Oberpfaffenhofen, Germany*
Tel: 49–8153–28–1470/ 1377, Fax: 49–8153–28–1445, e-mail: mschmidt@dfd.dlr.de

[2] *National Brasilian Space Research Institute (INPE), 12.227–010 S. Jose dos Campos, Brazil*

ABSTRACT

This work has been performed as part of a PH.D. thesis at DLR in Oberpfaffenhofen and at the University of Mainz. Data of the **ERS–1** satellite's **Active Microwave Instrument (AMI)** have been evaluated for their potential usefulness in **monitoring deforestation** and land use dynamics. The evaluation of SAR data has been performed in the **state of Rondonia** which is one of the **deforestation hot spots** in tropical rainforest of the **Brazilian Amazon**. A total of **5 ERS–1 scenes** have been used to perform the imaging work, data collected during a field campaign in 1995 served as reference data. The ERS–1 data have been acquired between June 1992 and October 1994. Image enhancement, filtering and **automatic classification** tools have been used to improve discrimination of land use classes and to analyse the images. As reference data several MLC–products of the **SIR–C/X–SAR** mission of April and October 1994 as well as **Landsat TM** data of July 1994 have been used.

1. INTRODUCTION

In 1989 a cooperation was started between DLR and the Brazilian Space Research Institute (INPE) in order to exchange scientists for field and computer work and to explore the possibilities given by remote sensing techniques to monitor the tropical rainforest.

The evaluation of SAR data has been in the focus of the scientific work since 1993 [Dos Santos, 1994]. Since November 1994 multifrequency–multipolarimetric SAR data of the SIR–C/X–SAR mission have been evaluated additionally. Main objective of the work with ERS–1 dâta was the evaluation of the possibilities to monitor land use dynamics and deforestation activies in the inner tropics. Further objectives were to discriminate and map landcover classes such as pastures, agriculture and soil degradation.

2. AVAILABLE DATA

A total of 5 ERS–1 Images were used. Three images. were GEC products, the other two were precision images (PRI). Three different dates were available for the test–site in Jaru, two dates for the test–site in the municipio Ji–Parana. The dates for the former are:

August 9th, 1992,
October 10th, 1993,
June 3rd, 1994.

The dates for the latter are:

January 15th, 1993,
April 30th, 1993.

All dates were from descending passes. The TM scene was recorded during July 15th, 1994.

3. TEST SITE DESCRIPTION

The test site in Rondonia has been chosen for two reasons. Firstly Rondonia has a very distinctive and rather unique clearcut pattern. Large and small–scale clearings form the typical fishbone pattern of many of the brazilian colonisation areas which pose quite different problems to image enhancement techniques such as filtering and automatic classification algorithms. Secondly Rondonia is one of the test areas of the international LBA–project (Large Scale Biosphere–Atmosphere Experiment in Amazonia) planned to start in the near future.

In Rondonia the local and national authorities have developed the PAD colonization scheme (**P**rojeto **A**ssentamento **D**irigido). Settlers in Rondonia will receive a lot of a certain size – which is 2000 m by 500 m (100 ha) – to cultivate. These areas are distributed in a certain pattern along development axes. These axes are laid out in a grid 4km apart. Theoretically each settler is allowed to clear 50% of his lot for cultivation. The intention was to keep a strip of 2 km broad forest between the pastures. Thus, soil loss through aeolian erosion was to be kept to a minimum and sufficient regenerating sources for the forest could be provided in case the lots were abandoned. Unfortunately the local settlers undermined this scheme by selling parts of their 100 ha lots to sub–owners who started clearing 50% of their sub–lots as well. So the actual forest cover in the PAD's dropped far below 50%, in some areas the forest strips vanished completely. Since the construction of the BR–364 (Brasil Rodovia) in 1984, the main paved

Proceedings of an International Seminar on The Use and Applications of ERS in Latin America, *Vina del Mar, Chile, 25-29 November 1996*
(ESA SP-405, March 1997)

highway connecting Rondonia with Acre and Mato Grosso do Sul, the stream of settlers coming to the state has increased considerably. Nevertheless, many of the colonists are not able to gain the desired piece of land and are forced to strive as seasonal workers at lowest wages [Walker, 1996]. Even the few happy enough to receive a lot are rarely able to support their families and are forced to move away from their lot after a few years either to start a new clearing cycle or to leave the state and migrate to the megacities in the south. In the early nineties the deforestation rate decreased due to diminished tax subsidies from federal government to increase again in 1995 to an even higher rate. In the course of clearing forests only a small part of the valuable trees are comercially used. Most settlers just cut and burn forest on their lots. The few logs which are harvested are used for pulpwood production or wood chips for power plants. A tiny fraction of the logs is used for local artwork or furniture production on a subsistence level. Lately the regional planning authorities, namely INCRA (Instituto Nacional de Colonizacão e Reforma Agraria) have taken steps to a stronger surveillance of settlement in Rondonia. Consequently INCRA has a strong interest in remote sensing data to observe and enforce the settling process.

4. CO-REGISTRATION

Three of the five ERS–1 scenes could be acquired as GEC products (Geocoded Ellipsoid Corrected). These were used to correct the incomplete rectification of the Landsat TM Scene which appeared slightly tilted to the north–east.

The ERS–1 data of Ji–Parana, the southern test area, were finally rectified to the corrected TM full scene. Fortunately, land use pattern and river maeanders provided sufficient ground control points to perform rectification.

5. IMAGE ENHANCEMENT

The Landsat TM scene showed zero percent cloud cover and no disturbing atmospheric haze or other influences disturbing quality and interpretability. So it was used for interpretation and automatic classification without further enhancement. The TM data were used to generate a forest/non–forest mask derived from the look–up tables of the channels 3,4 and 5. From this mask forest boundaries were extracted and used to check the forest/non–forest discrimination in the SAR–data.
The ERS–1 images were analysed using two different approaches. For visual interpretation a Gamma–MAP filter was applied in two iterations. The first filtering was done using a 3*3 moving window, the second iteration using a 5*5 moving window. This approach was chosen after various tests with FROST, LEE and Gamma–MAP filter and applying different window sizes. The applied filtering technique seemed best suited to enhance discrimination of forest/non–forest classes.

The ERS–1 data of the municipio Jaru proved not suitable for an analysis based on a multi–temporal overlay, as they showed information of the years 1992, 1993, 1994 respectively. Clearing activities changed the actual landcover to a point that no statistically relevant data could be extracted of the cleared areas, being forest in one year and pastures in the following. Multitemporal analysis was consequently limited to the southern test area in the municipio of Ji–Parana. Unfortunately, in this test area only two scenes could be acquired, one of December '92 and one of April '93. Thus, no multi–seasonal analysis in the actual sense could be performed as both scenes resulted from wet season.

6. AUTOMATIC CLASSIFICATION

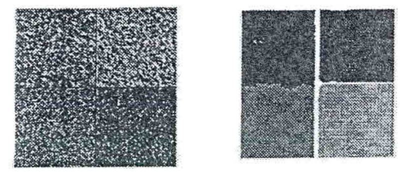
CLASSIFICATION METHODS APPLIED

For automatic classification purposes of SAR–images a set of training areas was used which was chosen according to data gained during a ground truth campaign performed in the year 1995 by the author and Dr. Dos Santos of INPE.

Half of the AOI's were used for training, the other half for evaluation of the classification result. For automatic classification two algorithms have been applied. On MAP–filtered images the maximum–likelihood method was chosen. In another approach unfiltered images were automatically classified using the EBIS (Evidence Based Interpretation of Satellite Images) texture classifier [Lohmann, 1991, 1994]. EBIS was applied to monotemporal images of 1992 and 1994 respectively, and to multi–layer images of the years '92 to '94.

The EBIS classifier uses local histograms and texture features described by co–occurrence matrices. EBIS is essentially a Bayesian classifier like maximum–likelihood. Therefore it needs a probability distribution to model its features. As local histograms and co–occurrences do not follow the Gaussian distribution EBIS uses the multinomial distribution and adapts the standard Bayesian approach to it. While the maximum–likelihood method defines class properties only by the grey value of a single pixel, EBIS goes one step further and uses co–occurrence matrices or local histograms in a defined window size. Co–occurrence matrices do not only record the relative frequencies of grey values but additionally record the relative frequencies of the spatial distribution of grey values in direct neighbourhood [Lohmann, 1994].

Position and form of the local histogram are determined in a moving window of definable size in the range of 5 to 15 pixels. In addition EBIS provides the possibility to use texture information either separately or in combination with the local histogram in up to 6 different feature space files. Experience shows that either one or the other option should be used. Feature space files contain the information of the statistical measures to be applied as well as the window size of the data space and the increments of grey levels to be used. The co–occurrence matrix may be calculated by using the following directions: horizontal, vertical, left–diagonal and right–diagonal. To save computing time it is advisable to use only two directions of the four as the additional information gain using all directions is minimal. Fig. 1 demonstrates the ability of the EBIS classifier to recognize texture and set–up different classes accordingly.



Texture Pattern   Classifcation Result

Fig. 1: (Source: Lohmann, 1995)

Fig. 2 shows an example of a class which is clearly distinguishable for the human eye but still has the same histogram. By using the co–occurrence for the class decision EBIS is capable to separate the two classes in the sample shown above. In this approach various grey level and window sizes were tested. The classification results on multi–layer and one–layer images were compared.

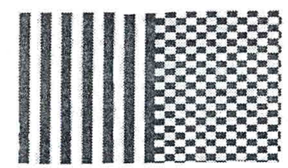


Fig. 2: Two different texture with identical histograms (Source: Lohmann, 1995)

Fig.3 shows the influence of EBIS window sizes on the classification result. The difficulty for the human interpreter and user of EBIS is to pick the classes according to their textural features. Experience has shown that here only a small number of training polygons or AOI's (areas of interest) is needed and that the AOI's should enclose an image area large enough to generate a sufficiently distinctive class statistic based on the co–occurrence matrix.

CLASSIFICATION RESULTS

Strong limitations are caused by the wave–length of ERS–1 operating at C–band and its VV–polarisation. Thus, working with a low penetration depth in the substrate, ERS–1 has a limited capability to discriminate classes like primary rainforest and older regenerating areas of an age higher then 4 years [Keil et al., 1995].

This has to be accounted for when trying to set–up a monitoring system or using automatic classifiers. The first step, however, in automatically classifying the ERS–1 data is to define target classes to be extracted. Due to the limitations of ERS–1 a mixed class of *Forest* and *Regrowth* older than 4 years had to be defined. Other visually separable classes were *pasture in good condition* and *degraded pasture* showing a vegetation cover lower than 40 percent. In the southern test–area another limitation of the ERS–1 sensor became evident. Due to the incidence angle of 23.5 degrees images of slopes of the same angle or similiar angle towards the sensor contain only little information. This effect severely degrades the interpretability of the ERS–1 image of the Ji–Parana test–site, as the southern part consists of quite hilly terrain. This is amplified by the nature of the slopes appearing in this area. Most hills consist of blocks of quarzit, resistent to erosion. This has the effect that many slopes have angles steeper then 45 degrees. Also the stronger shaded parts of hilly terrain lead to misclassifications, especially with the class *degraded pastures* (see Fig. 4). The adjacent Table 1 gives a first assesment of classification accuracies for the forest/non–forest discrimination by EBIS, derived from 6 evaluation areas for each class. Within these areas a set of 100 points was chosen randomly to calculate the statistics.

Class name	Producer's Accuracy	User's Accuracy
Rainforest	67,57 %	100 %
Non–Forest	100 %	52 %

Overall classification accuracy: 76 %

Table 1: Confusion Matrix for Forest/Non–Forest Discrimination

HIERACHIC CLASSIFICATION APPROACH

Experimenting with the classifier showed that a hierachical classification approach seemed best suited to separate the *forest/older regrowth* mixed class from the classes *pasture* and *degraded pasture.* In a first step EBIS was used to separate forest/non–forest. From this a mask was generated by recoding the classification result to a binary image. The mask was used to cut out the mixed class *forest/older regrowth.* The remaining classes were in a first approach MAP–filtered twice as described above and then the maximum–likelihood classifier was used to further separate the classes *pasture* and *degraded pasture.* To the unfiltered masked image EBIS again was applied. The results of both operations were compared. This scheme proved to be quite successful in discriminating the classes *pasture* and *degraded pasture* (see Fig. 5).

7. CHANGE DETECTION

The technical features of C–band sensors pose rather strong problems to an accurate mapping of rainforest. Even by using multi–seasonal approaches the discrimination of forest and older regrowth classes does not improve. Nevertheless, the constant availability of the data should and can be used for a monitoring system. The idea is to use optical data of SPOT or Landsat TM as a baseline for a classification of the area. By setting up forest maps derived from these data, change detection can be performed visually and to a certain degree by automatic classifiers. Land use changes can be further enhanced by simply subtracting images of subsequent dates (see Fig. 6). ERS–1 data and especially multi–seasonal stacks of ERS–1 data have the ability to show changes in landcover. This can be used as an additional, quasi continuous information source to survey rainforest areas.

8. CONCLUSIONS

The objectives of this work were to evaluate the usefulness of ERS–1 data for monitoring rainforest destruction and land degradation in the tropics. To a certain degree this could be achieved. Monitoring fresh clearcuts is possible with respect to certain restrictions given by the technical design of the sensor. Discrimination of rainforests and regrowth is depending on moisture and therefore seasonality. The discrimination seems better in the dry season due to the larger difference of biomass cover of the areas. Fresh clearcuts could be separated from agriculture. Pastures could be discriminated of degraded soils and fresh clearcuts. Both applied automatic classifiers have problems in areas of high relief. The shaded and the strongly illuminated areas could not be separated from the classes *degraded pasture* and *settlements*, respectivly.

Also, problems tend to appear in areas of initial clearing stages when the first fire has been laid and remnants of the trees are still emerging from the ground. These remnants have a similiar backscatter as *forest* or *older regrowth* areas. Here a combined analysis of L–band and C–band data seems to promise further improvement in discrimination of classes containing vegetation with higher biomass levels.

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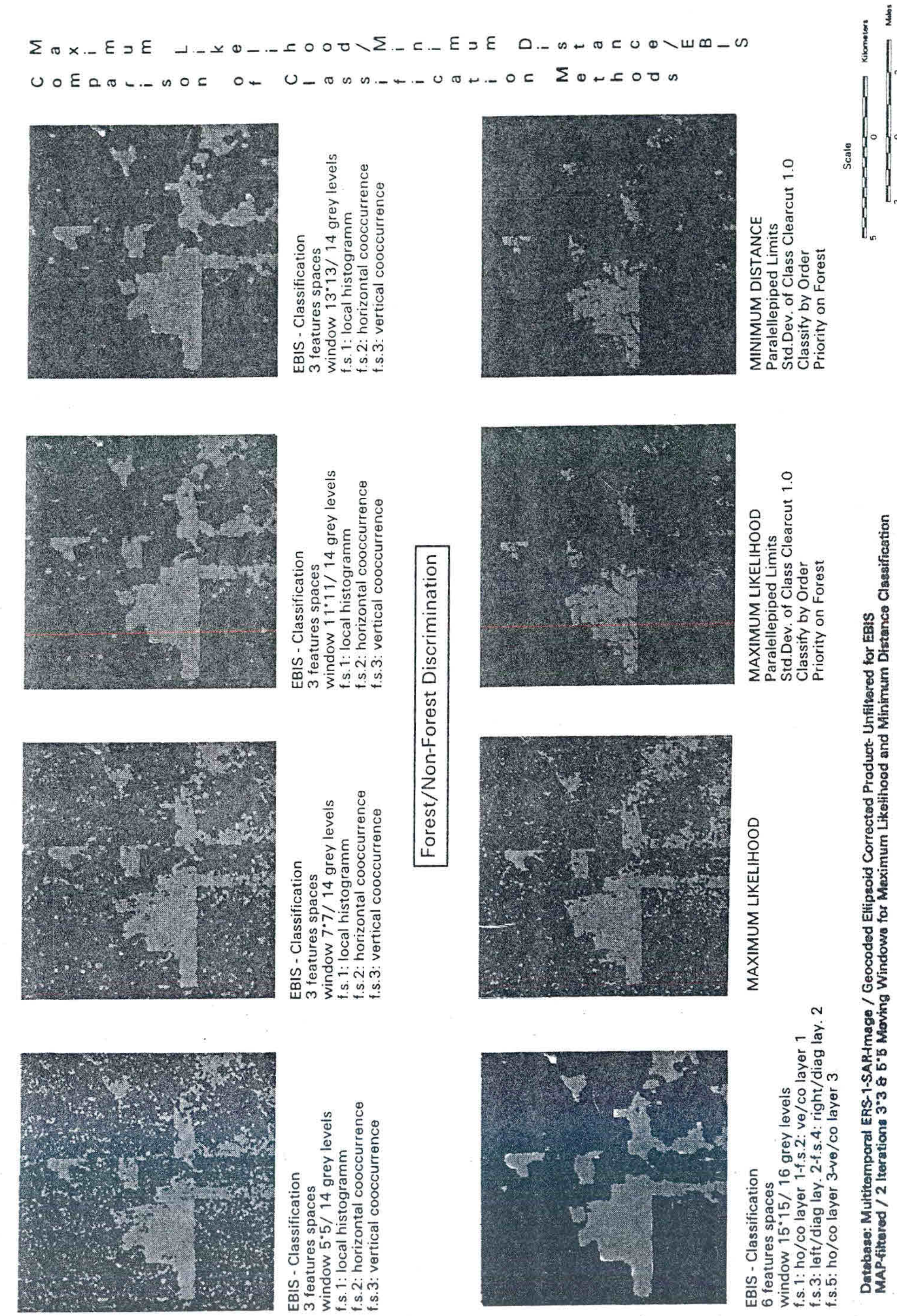

Fig. 3: Comparison of EBIS classification (different window sizes) with Max. Likelihood / Minimum Distance

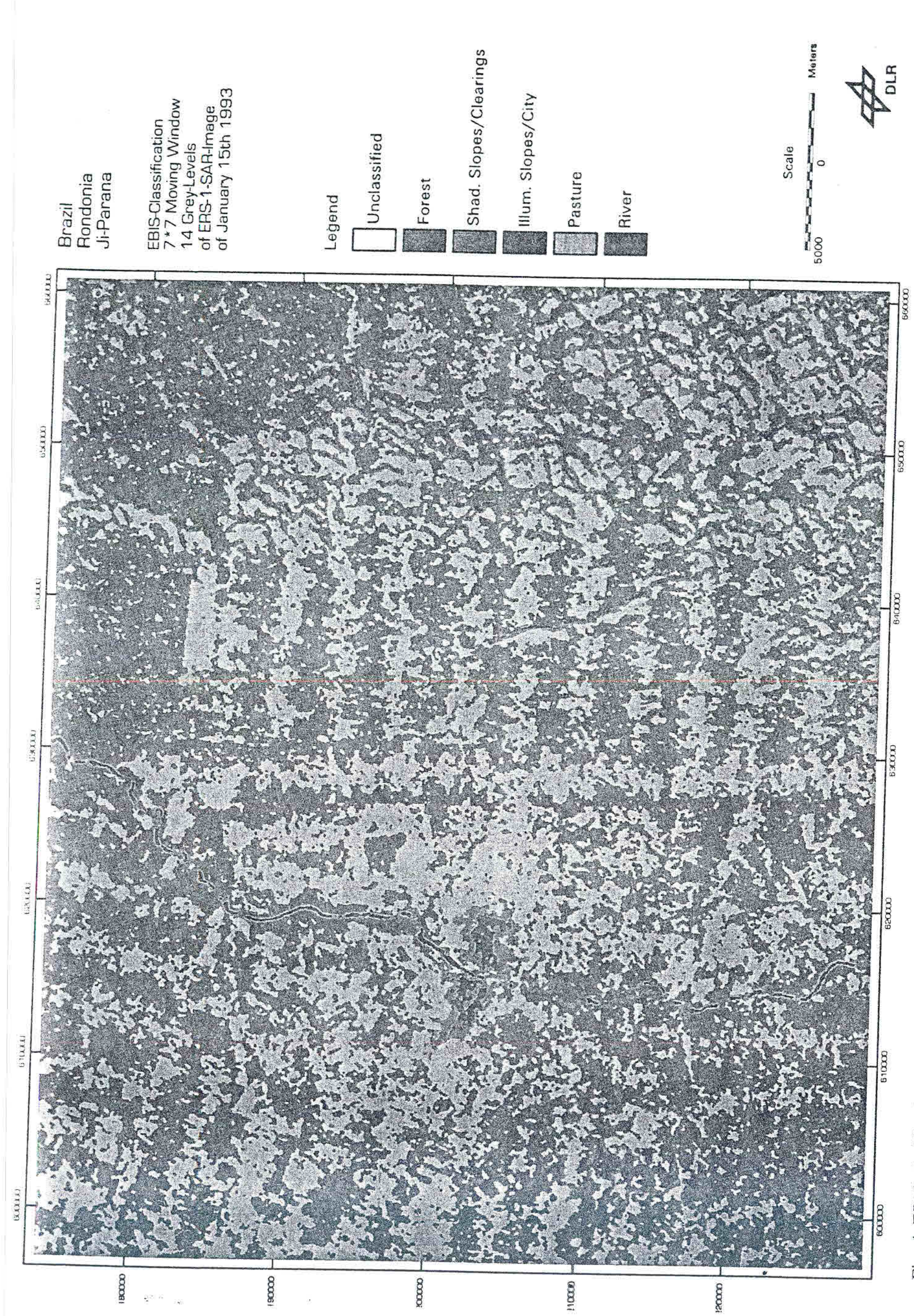

Fig. 4: EBIS clasification result in hilly terrain

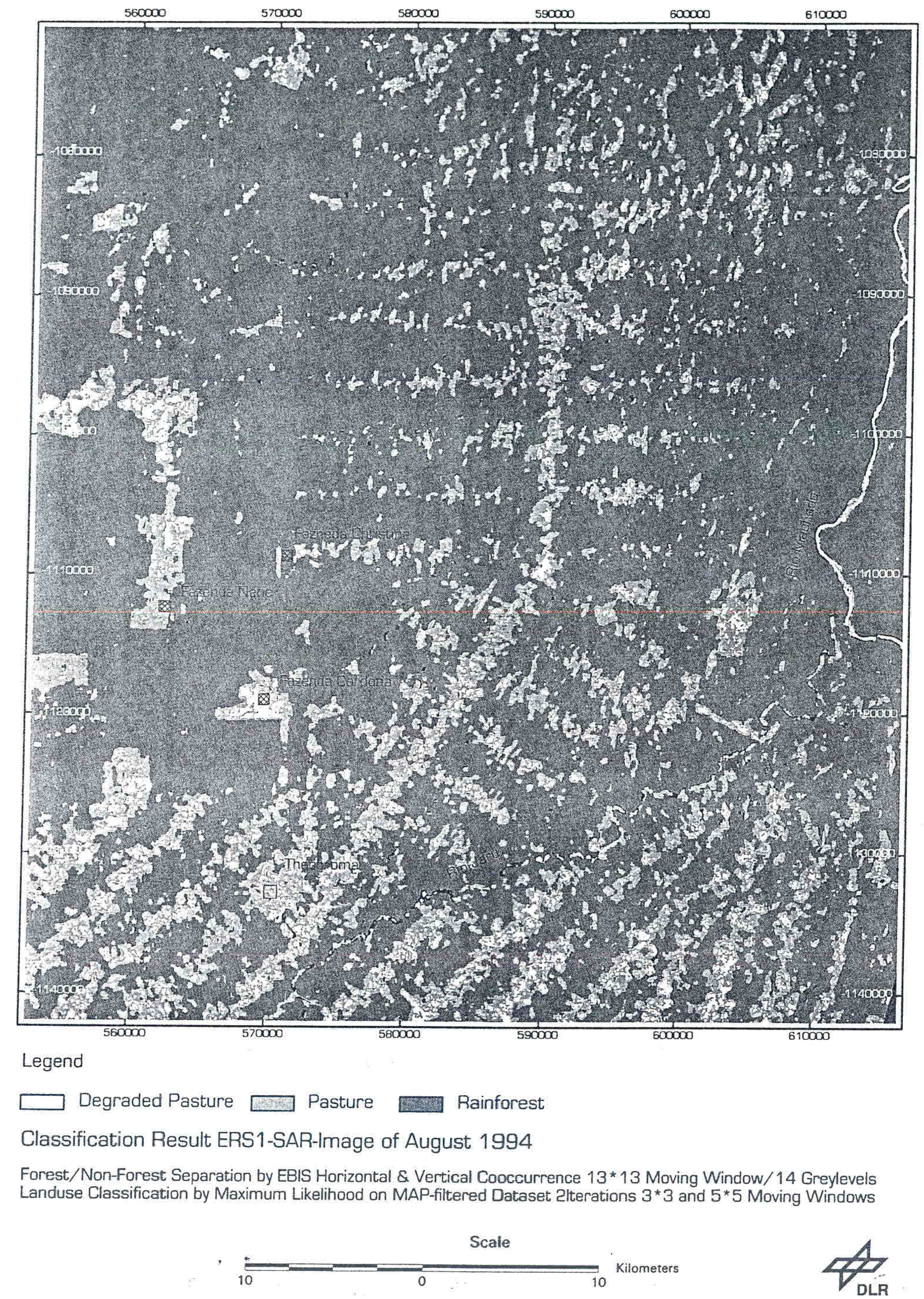

Fig. 5: Hierarchic classification approach by combining EBIS and Max. Likelihood classification

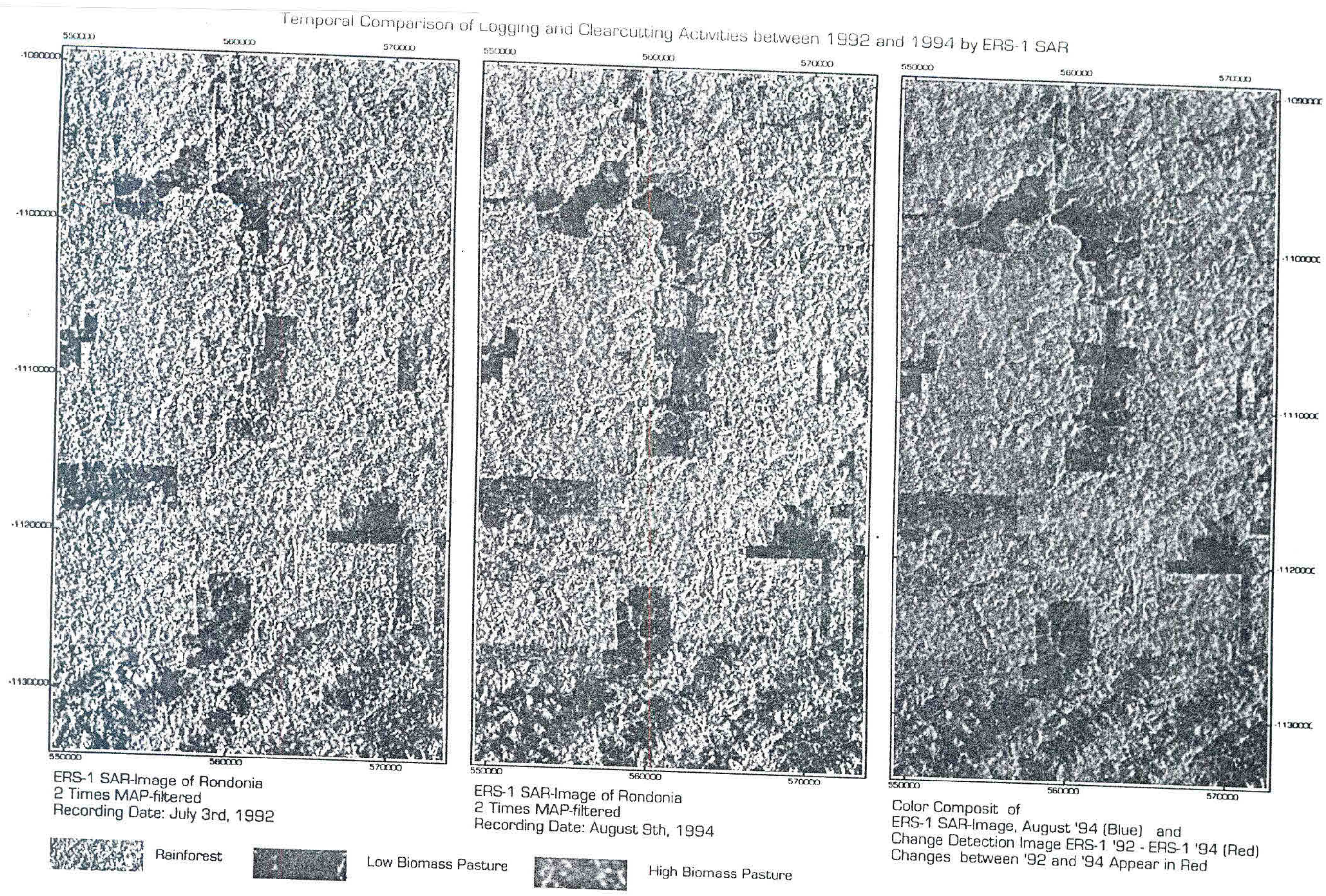

Fig. 6: Example for representing change detection