MONITORING THE AMAZON WITH DIFFERENT SPATIAL AND TEMPORAL RESOLUTION

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KEY WORDS: Forestry, Monitoring, Combination, Radar, Resolution, Spatial, Temporal

ABSTRACT:

When monitoring deforestation, frequent images with an optimal spatial resolution are required. But in reality either images with low spatial resolution and a high revisit frequency or high spatial resolution images with a low revisit time are available. Combining different spatial and temporal resolutions could solve this problem. The study site in the Colombian Amazon contains small fields within the forest. The input data consisted of one high spatial resolution AIRSAR image and a time series of nine ERS-1 images of medium spatial resolution, and their supervised classifications. The AIRSAR image was upscaled with stepwise upscaling based on interim results and by direct upscaling from the same basis to different levels of spatial resolution. The comparison showed that the proportion of land cover classes did not change substantially in either of the two upscaling approaches, while the number and size of the patches showed a clear decrease with continuing upscaling. The direct upscaling approach provided best results. Furthermore, the conformity of the upscaled AIRSAR land cover map and the ERS-1 land cover maps was determined. For the study area with its particular land cover pattern, the effect of the spatial resolution on classification was not as important as expected. The fact that AIRSAR has three fully polarimetric bands, while ERS-1 has only one band and one polarization was a more important cause for differences between the land cover maps than the differences in spatial resolution.

1. INTRODUCTION

The Amazon forest is the largest tropical forest in the world. The Greater Amazon region in South America has to cope with large amounts of damage from deforestation affecting the region itself, as well as global ecosystems through its influence on climate and hydrology. Many governmental and non-governmental organizations are therefore interested in regular updates of information on the forest. Monitoring based on remotely sensed imagery is a logical choice, because the area is vast and inaccessible. Previous research on tropical deforestation used images with low spatial resolution (e.g. Cross et al., 1991; Malingreau et al., 1989; Mayaux et al., 1995) as well as medium spatial resolution imagery (e.g. Skole et al., 1993).

When monitoring the earth's surface with remote sensing, problems like high costs for high spatial resolution imagery and image processing as well as spatial and temporal resolutions that are sub-optimal for the process to be monitored are encountered. If monitoring a process over a specific time, one will need frequent images with an optimal spatial resolution. But in reality either images with low spatial resolution and a high revisit frequency or high spatial resolution images with a low revisit frequency are available. A combination of imagery with different spatial and temporal resolutions may be considered to overcome these problems, e.g. to reduce costs and time of image acquisition and processing while maintaining required spatial and temporal detail.

For a number of change processes, both the process itself and its speed are known or can be predicted across the study area. Deforestation occurs mainly and most rapidly along the fringes of the forest and close to roads and rivers.

Much research has already been carried out on integration of data of different spatial resolution and the generalization of data. However, the temporal dimension, how this works out in a monitoring system has not received so much attention yet. Thus it is of particular relevance to focus the research on combining the spatial and the temporal aspect.

1.1 Research objective

The objective of the research is to assess whether a combination of low spatial resolution and high spatial resolution imagery gives better results than only using frequent low spatial resolution or only infrequent high spatial resolution.

1.2 Research questions

Does a combination of low spatial resolution and high spatial resolution imagery give better results, in terms of higher accuracy, more thematic detail, than only using frequent low spatial resolution or only infrequent high spatial resolution?

- Did the upscaling method affect the results of the classification of the high spatial resolution data? And if so, how?
- Did parts of the data or information get lost or could new information be gained during upscaling?
- What kind of pattern change occurs with a change in the resolution?
- What is the degree of conformity between low and high spatial resolution data?
- Can the better spatial detail of the high spatial resolution images be interpolated over time while using low spatial resolution images?

2. STUDY AREA

The study area is located on the northern fringe of the department of Guaviare in the Colombian Amazon. It extends from the capital of the department, San José del Guaviare, 30 km south to El Retorno from latitude 2°35' to 2°20' north and from longitude 72°47' to 72°35' west (Bijker, 1997).

Figure 1. Location of study area

2.1 Land cover

Before the 1950's, tropical evergreen rain forests covered a larger part of the area. Due to the process of colonization, extensive parts have been deforested and replaced by crops, pastures or dense secondary vegetation. Besides the evergreen rain forest and the human influenced vegetation, savannahs also exist in the study area.

2.2 Land use

In the uplands pasture for cattle breeding is the dominant land use in cleared areas. The following process will mostly be applied to convert the forest into pastures: first the primary or secondary forest will be cut and burned, after that perennial crops (e.g. cacao, plantain) and annual crops (e.g. maize, rice) are planted. A smaller part of the area will be planted with more permanent crops like rubber, fruit trees, sugarcane and coca. The number of years a field is used for crops can vary, but after a view years of cultivation it will be left fallow or turned into pastures (Bijker, 1997).

In the alluvial plain of the Guaviare river agriculture is the main land use. The soils are more fertile than in the uplands, therefore the crop yields are higher in the alluvial plain. The main cultivated crops are bananas, cacao, maize, soybean, cotton, sesame, cassava and sugarcane (Bijker, 1997).

3. DATA AND METHODOLOGY

The input data in this research consist of one C-, L-, P-band polarimetric AIRSAR image of May 1993 with a spatial resolution of 6 m (Hoekman et al., 2000) and a time series of nine ERS-1 images from May 1992 until September 1994 with a spatial resolution of 12.5 m as well as the land cover maps derived from these images (Bijker, 1997). The land cover maps were based on all ERS-1 images available till that date.

Common land cover classes are needed to facilitate the comparison between the classifications of the high spatial resolution image and the lower spatial resolution images. In this research four land cover classes were used: primary forest, secondary forest, pastures and recently cut areas.

Furthermore, spatial scaling is needed. Spatial scaling takes information at one scale and uses it to derive processes at another scale (Jarvis, 1995). This can be either upscaling, where information at a higher spatial resolution is taken and transformed to the lower spatial resolution or downscaling, which works in opposite direction (Jarvis, 1995). In this case upscaling of the high spatial resolution AIRSAR land cover map was applied.

Two processes will be applied to the high resolution AIRSAR data. First, the classification of these data, as made by Quiñones (1995; Hoekman et al., 2000) will be upscaled. The outcome is referred to as AIRSAR land cover map 1 later on. Secondly, the original AIRSAR image will be upscaled first and subsequently classified. This result is referred to as AIRSAR land cover map 2.

Two different approaches for upscaling were evaluated in order to determine their effect on proportional area of land cover classes and to detect changes in the number and size of the patches of the AIRSAR land cover map during the upscaling process as well as to select the most eligible procedure to upscale the AIRSAR data to 12.5 m, the resolution of the ERS-1 land cover maps. Finally, the classified ERS-1 images of Bijker (1997) were compared with the upscaled AIRSAR land cover maps to assess their conformity.

This research refers to pixels. According to Bian (1997), only objects that operate at a scale larger than the size of the pixel can be revealed during upscaling. But it also needs to be mentioned, that small objects, which have a high contrast with their surrounding area, may be detectable even if they are smaller than the pixel size. However, at a high spatial resolution pixel sizes are mostly smaller than objects of interest. Therefore, the neighbouring pixels are highly correlated and a low variance exists among them. With an increase in the pixel size, the similarity decreases and the variance increases (Rahman et al., 2003; Woodcock et al., 1987).

4. RESULTS

4.1 Evaluation of different upscaling approaches

The first approach implies stepwise upscaling in half-meter steps, beginning with the AIRSAR land cover map 1 of 6 m resolution until the resolution of 12.5 m was obtained. The stepwise upscaling is based on each previous interim result. The second approach used direct upscaling to different levels of spatial resolution each based on the 6 m resolution AIRSAR image. The two approaches resulted both in 14 upscaled AIRSAR land cover maps of different spatial resolutions.

In order to calculate the new output pixels, the nearest neighbour resampling method was applied, because it uses the nearest pixel without any interpolation to create the resampled image. The original pixels are simply relocated onto a geometrically correct map grid.

4.1.1 Changes in proportion of land cover classes

Research regarding problems of upscaling high resolution remote sensing data showed, that it can be assumed that in general the proportion of land cover classes will decrease with continuing upscaling to lower spatial resolution while the proportion of unclassified pixels will increase (Gupta et al., 2000). An aggregation of classes will occur.

	Primary forest	Secondary forest	Pastures	Recently cut areas
AIRSAR map	68.41%	17.98%	6.51%	7.11%
Approach 1	68.39%	17.94%	6.70%	6.97%
Approach 2	68.08%	18.17%	6.63%	7.11%

Table 2. Comparison of upscaling approaches based on the proportion of land cover classes

In this research, upscaling was done by nearest neighbour resampling of classified data, so there was neither a problem of class aggregation nor of an increase of unclassified pixels.

As shown in Table 2, both in the first and in the second upscaling approach barely any change in the proportion of land cover classes could be discovered. By comparing the percentages of the land cover classes, it can be seen that the proportions stayed almost the same.

4.1.2 Changes in number and size of patches

As another possibility to detect changes caused by the process of upscaling of the AIRSAR land cover map, unique identifiers were assigned to the pixels with the same class names that are horizontally, vertically and diagonally connected. This was applied for each upscaling step. These connected areas are called patches, since a patch is a set of neighbouring pixels of the same class. The output was a map in which the connected areas are coded. Furthermore, an attribute table was created for the output map containing the size of the unique output units.

A 3 x 3 filter was moved over the map and a value was assigned to the centre pixel of the filter in the output map depending on the values of the centre pixel itself and its eight neighbouring pixels in the input map.

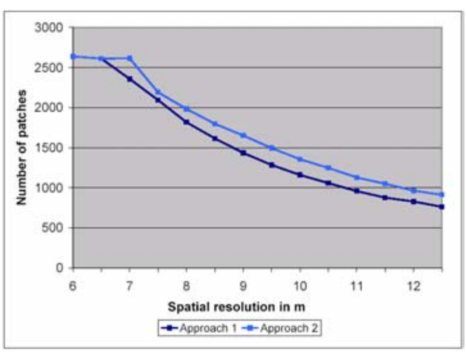

Figure 3. Comparison of upscaling approaches based on the number of patches

By comparing the two upscaling approaches, a strong decrease in the number of patches was found in both. In the first approach, stepwise upscaling with interim results, 763 out of 2638 patches remained at a resolution of 12.5 m. In the second approach, direct upscaling to different levels from the same basis, 913 patches out of 2638 remained. As shown in Figure 3, both curves have a similar course with a small difference along the y-axis. Nevertheless, the direct upscaling approach gave a larger number of remaining patches and better visual results. Furthermore, the size and the shape of the patches were kept longer during the direct upscaling process.

With regard to the size of the patches, it can be stated that in both upscaling processes small patches loose their shape or disappear during upscaling to lower spatial resolution and bigger patches remain longer and keep their recognizable shape as well.

4.2 Conformity of land cover maps

The conformity of the land cover maps was determined with the help of the so-called cross operation. This operation performs an overlay of two land cover maps and compares the class values on the same positions in both maps. The combinations of class values that occur are stored. The output is a cross map and a cross table. The cross table includes all combinations of the input classes of both maps and the number of pixels for each combination. With the help of the cross table a cross matrix is calculated to compare two land cover maps by evaluating the number of matching pixels.

Land cover class	Conformity
AIRSAR and ERS-1 (until 28-09-1993)	
Pasture	59%
Pasture and secondary forest	0%
Primary forest	91%
Recently cut areas	0%
Secondary forest	16%
AIRSAR and ERS-1 (until 05-09-1994)	
Pasture	63%
Pasture and secondary forest	0%
Primary forest	86%
Recently cut areas	0%
Secondary forest	24%

Table 4. Conformity of cross maps

When assessing the conformity of two land cover maps, the same logic as in an ordinary confusion matrix is used. Not the single classification but rather the difference between the two classifications is considered. Nevertheless, the outcome of a cross map is strongly influenced by the accuracies of the two independent classifications used for the cross matrix. Classification errors in either of the classifications could result in non-conformity of classes.

According to Quiñones (1995), the results of the classification of the original AIRSAR image indicate that 89% of the secondary forest, 100% of the pastures, 97% of the primary forest and 92% of the recently cut areas were classified correctly. Consequently, the overall accuracy is 95%. The overall accuracy of the ERS-1 land cover maps varies with time from 65% to 70%, but they contain a mixed class of pasture and secondary vegetation. The pixels of this mixed class were included into the other classes, which influences the result of the conformity. The mismatches occurred mainly between this mixed class of the ERS-1 classification and the AIRSAR land cover classes secondary forest and pastures.

First, the ERS-1 land cover map of 28-09-1993 was chosen because it has the same year of acquisition as the AIRSAR image. The low value for the conformity of the secondary forest is influenced by the mixed class pasture and secondary vegetation of the ERS-1 land cover map, but also by the fact that the ERS-1 sensor has difficulties in separating the secondary forest from primary forest and pastures. The cross operation was also applied to the AIRSAR land cover map 1 and the ERS-1 land cover map of 05-09-1994. This cross operation achieved the best results.

Mismatch occurred mainly in areas classified as secondary forest in the AIRSAR classification and as primary forest in the ERS-1 classification, which is most likely due to mis-classification of secondary forests in the ERS-1 classification. Furthermore, the pastures of the AIRSAR classification have mismatches with the secondary forest of the ERS-1 land cover map.

The conformity of the cross maps between the AIRSAR land cover map 1 and the selected ERS-1 land cover maps is presented in Table 4. The recently cut areas were all classified into other classes. In the ERS-1 images these areas were not detectable and therefore they could not be classified, but in the AIRSAR image the recently cut areas were clearly visible and consequently also classified.

Similar results were achieved for the conformity of the second AIRSAR land cover map and the ERS-1 land cover maps.

4.2.1 Discussion

To understand the results of the cross operations, the input classifications need to be considered. The original data, i.e. the AIRSAR land cover maps and the ERS-1 land cover maps, show already differences when comparing them visually, but also concerning the number of classes, the classification accuracies, the number of bands and polarizations.

The AIRSAR land cover maps show more details. In the upscaled AIRSAR maps, several small patches of the other classes can be distinguished within the large area of primary forest. In the ERS-1 maps these cannot be differentiated. But also large areas, e.g. parts of the secondary forest and of the pastures were not classified correctly in the ERS-1 maps. With regard to the size of the patches or the number of pixels in a patch, the small patches have a large number of boundary (mixed) pixels and few interior (pure) pixels, which can lead to non-detection and misclassification. Large patches have a large number of interior (pure) pixels relative to the fewer boundary (mixed) pixels, so they have a higher chance to be detected and classified correctly.

Four pure land cover classes can be distinguished clearly in the AIRSAR land cover maps, while the ERS-1 land cover maps have three pure classes and one mixed class. The class recently cut areas could not be detected in any of the ERS-1 land cover maps. Due to the start-up of the ERS-1 monitoring system developed by Bijker (1997), not every change was detected immediately with the image of 28-09-1993 or with the image of 05-09-1994. The land cover changes detected with the images consist of real, recent land cover changes and the learning effect of the monitoring system, detecting "old" changes not yet registered. Due to this learning effect, classes were detected afterwards that were there but could not be detected earlier.

The AIRSAR land cover map has an overall accuracy of 95%, while the overall accuracy of the ERS-1 land cover maps ranges from 65% till 70%. In the original ERS-1 land cover classifications the accuracy for the secondary forest was already low. It reached only 43%. On the other hand, the pastures showed a relatively high accuracy (86%) in the ERS-1 land cover maps, since they were relatively well distinguishable from the other classes.

Furthermore, the AIRSAR sensor has three bands, the C-, L- and P-band, all fully polarimetric. These bands are complementary. The combination of the three bands and their polarizations makes it possible to accurately separate the four land cover classes: primary forest, secondary forest, pastures and recently cut areas. The ERS-1 sensor has only one band, the C-band, with only VV polarization. Consequently, the upscaled AIRSAR land cover maps present more information and a bigger variety of objects with different shapes and sizes than the ERS-1 land cover maps.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions regarding upscaling

Both upscaling approaches, stepwise and direct, showed similar results. Nevertheless, the second approach, direct upscaling from the same basis to the desired levels of spatial resolution, was selected because it presents a slightly better outcome concerning the changes in the number and size of patches. Another advantage of this approach is the shorter processing time for the implementation of upscaling, since the interim results do not need to be calculated. The upscaling leads immediately to the desired output pixel size.

5.2 Conclusions regarding land cover maps

The cross operation between the AIRSAR land cover map 1 and the ERS-1 land cover map based on the image of 05-09-1994 provided best results, since it resembles best the AIRSAR land cover map 1, despite of the time lag of one year.

General reasons for non-conformity of classes can be errors in geo-referencing or in upscaling as well as errors within the input classifications. Apart from failures of detection or mis-classification in the input land cover maps caused by mixed pixels along boundaries of patches, the differences in the number of spectral bands and polarization between the original AIRSAR image and the ERS-1 images cause differences in the classification accuracies of the input data. For this study area with its particular land cover, the effect of the spatial resolution is not as determining as expected.

Concerning the order of upscaling and classification, it was found that both possibilities provide similar results. It has to be mentioned that upscaling before classification can add un-certainty to the pixel value. The classification accuracy could be prejudiced accordingly. Therefore, it is suggested to apply classification before upscaling.

The combination of low spatial resolution and high spatial resolution imagery gives better results than only using frequent low spatial resolution or only infrequent high resolution. With the help of high spatial resolution data the information from the lower spatial resolution data can be improved. Locations of classes can be derived, failures in classification can be corrected and consequently the accuracy will improve.

5.3 Recommendations

Since the effect of spatial resolution was less determining than the number of bands and polarizations of the sensor, it can be suggested to use another radar sensor for the monitoring system of this particular study area. A sensor is needed that is able to detect land cover changes, in particular deforestation, with lower spatial resolution than the AIRSAR sensor, but with more bands and more polarizations than the ERS-1 sensor. Especially bands with larger wavelengths are needed to improve the accuracy of the classification of secondary vegetation.

Another possibility can be using high spatial resolution data to derive information (e.g. the location of recently cut areas) and to correct misclassification. Therefore, it is recommended to include the AIRSAR data in the ERS-1 monitoring system proposed by Bijker (1997) in regular intervals either at the initial stage and/or at a later stage. It can be expected that the location of those classes, which could not be detected properly in the ERS-1 images, such as secondary forest and recently cut areas, becomes known and so the accuracy of later ERS-1 classifications will be improved by including this knowledge. Nevertheless, field observations should still be included, specifically in areas showing non-conformity between high and lower spatial resolution data.

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ACKNOWLEDGEMENTS

The authors would like to thank Marcela Quiñones and Dirk Hoekman for providing their AIRSAR data and classification.