Remote Sensing and GIS for Site Characterization

Applications and Standards

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Contents

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A Change Detection Methodology for the Amazon Forest Using Multitemporal NOAA/AVHRR Data and GIS—Preliminary Results

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ABSTRACT: This paper describes initial results of a methodology developed to locate new deforestation in the Amazon Tropical forest. It combines automatic classification of the Advanced Very High Resolution Radiometer (NOAA/AVHRR) satellite images and a Geographic Information System (GIS) data base. Full resolution and geometrically corrected AVHRR channel 3 (3.7 μm) images of different dates of the Amazon region are automatically compared in digital form. Places where changes in the original cover of the vegetation are detected between any two different images have their locations determined through a GIS. Initial tests in the north of the state of Mato Grosso, Brazil, are presented indicating the possibility of using AVHRR imagery operationally to detect new deforestation. Results comparing deforestation in the AVHRR channel 3 with corresponding high resolution LANDSAT-Thematic Mapper (TM) images indicated 56.5% of AVHRR correct location for 221 polygons of deforestation with different sizes. 90% of correct locations was obtained for the 50 TM polygons with deforestation greater than 3.1 km^2.

KEYWORDS: Amazon, AVHRR images, deforestation, GIS, remote sensing

The rapid change in tropical forests and particularly in the Amazon vegetation cover has been causing an increasing global concern in association with its impact on the environment (Sagan et al. 1979; Sioli 1987; Salati and Nobre 1991). Considering the dynamic of tropical forest cover change (Sader and Joyce 1985; Fearnside 1989; Woodwell et al. 1987) the use of remotely sensed data plays an effective role in environmental programs. In recent years the Advanced Very High Resolution Radiometer (AVHRR) sensor, aboard the National Oceanic and Atmospheric Administration (NOAA) meteorological satellites, has had significant impact in vegetation studies (Justice et al. 1985; Malingreau and Tucker 1988; Cross 1991). The use of the AVHRR 1.1 km maximum spatial resolution has many advantages because of features like low cost of images, daily coverage, capability of near real-time receiving and processing of images covering areas of continental dimensions (Kidwell 1991), the main limitation is its relatively coarse resolution.

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Processing and applications of the large amounts of data available from orbital remote sensing systems are time-consuming tasks. One of the ways that reduces this problem and optimizes the analysis of data, is the use of Geographic Information Systems (GIS) (Ehlers et al. 1989).

The objective of this work was to test a methodology for a semi-automatic operational system to identify new deforestation in the Amazon Tropical Forest, combining multitemporal AVHRR data and a GIS on a short-time and low-cost basis. Such a system is needed to detect new deforestation sites in the monitoring of the world's largest rain forest.

Materials and Methods

The study areas are located in the Brazilian Legal Amazon, in the state of Mato Grosso. They are part of a rectangle of about 666 km × 444 km covered by sixteen standard maps at the 1:250,000 scale. Five areas, each one corresponding to a specific map (Fig. 1), were used to test the methodology of deforestation detection.

Two AVHRR (Advanced Very High Resolution Radiometer) channel 3 (3.55–3.93 μm) full 1.1 km resolution images of the NOAA-11 satellite from the 1990 dry season (30 July and 15 September) covering the Brazilian Amazon Forest were used. Channel 3 images were preferred following the work of Amaral

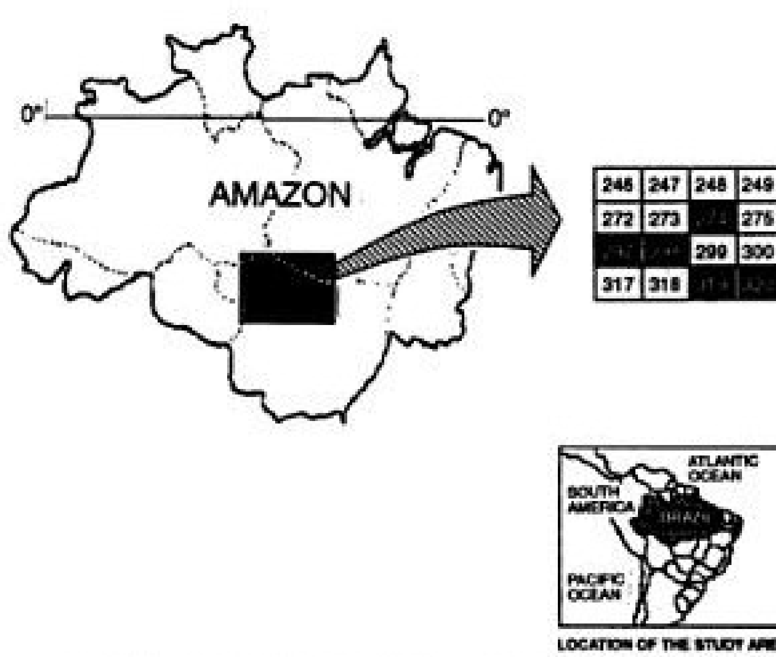

FIG. 1—*Study area, and MIR map sheets 274, 297, 298, 319, 320.*

1992, which showed this channel to be the best AVHRR resource to discriminate forests from non-forest covers. Figure 2 shows the channel 3 image for the study area with geometric correction, but without any digital processing for the vegetation cover; no other AVHRR channel or combination of channels had such clear separation of forest × non-forest cover. In this image, the dark areas clearly show non-forest cover, associated either with new or old deforestation. The changes in the forest cover between the dates of the two AVHRR images were analyzed in a GIS developed by the Brazilian National Institute for Space Research—INPE (Souza 1990). The image processing was carried out in an PC-based 8-bit/256 digital counts image processing system known as SITIM and also developed by INPE (Souza 1990).

Because a single composite resulting image was to be produced the raw images were geometrically transformed and overlaid; this was achieved applying a correction algorithm (Fernandes 1993) to each scene. This also removed imaging distortions, and created pixels of equal size (1.1 km × 1.1 km) throughout the image. Another algorithm [*14*] was used to identify cloud pixels so that they were not misclassified as forest. Cloud pixels were identified in channel 2 and had the gray-level of 255 allocated in channel 3, thus corresponding to the coldest temperature level.

The two AVHRR channel 3 scenes were processed using a single-cell classifier. It is a supervised technique, and in this case of just one spectral channel, corresponds to the division of the gray-level scale in classes—or "slices." As the scenes were acquired on different dates, each one was classified choosing different limits for each class, based on the histograms of the digital counts of the pixels in the respective images. The classes chosen were the following: forest, deforestation, and cloud. Samples of areas of forest in each image were analyzed so that their respective threshold classification limits were established.

The two classified images were imported to the GIS, where the temporal analysis was carried out. The GIS allows the digital cross-comparison of two images in order to create another one according to rules established by the user. In this case, a reference layer resulting from the difference of the two images was produced and this layer made possible the analysis of change

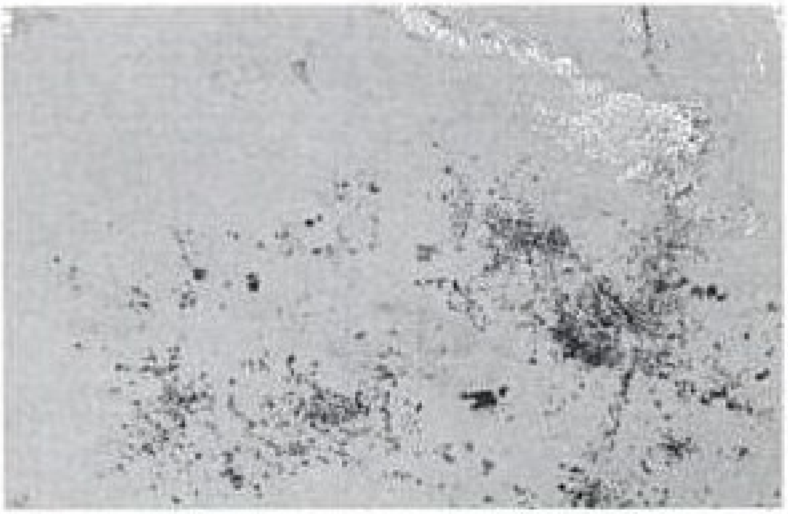

FIG. 2—*Study area (8° to 10° latitute S and 54° to 60° longitude W) in the AVHRR channel 3 (3.55–3.93 μm) image of 15 September 1990: darker tones indicate deforestation in general.*

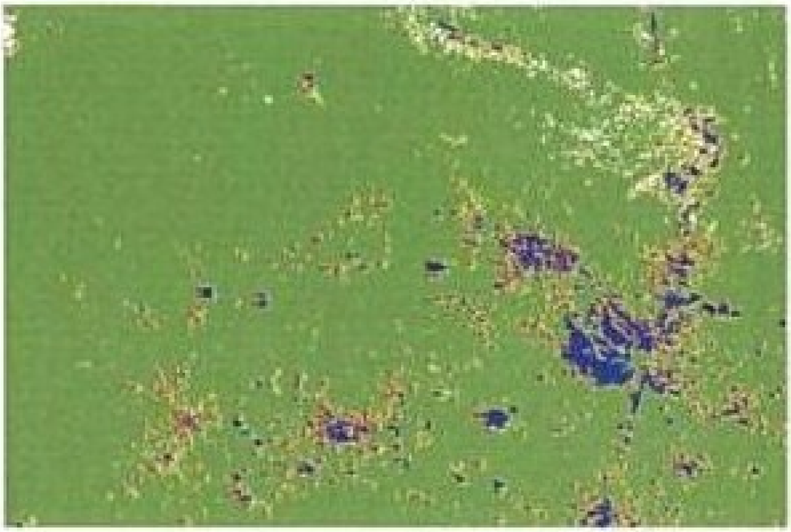

FIG. 3—*"Difference AVHRR Image" for the study area (8° to 10° latitude S and 58° to 60° longitude W) showing new deforestation in red.*

detection in the Amazon forest (Mantovani 1994). Figure 3 presents the "difference image" of the two distinct channel 3 images used, where the following categories/colors were applied:

- green = forest cover in both dates;
- blue = non-forest cover in both dates (old deforestation and "cerrados");
- red = new deforestation (deforestation detected from July to September 1990);
- orange = regrowth (mainly secondary vegetation growth);
- white = clouds.

Validation

The validation of this study consisted in a comparison between TM-Landsat and AVHRR-NOAA data. The extent of forest clearing derived from TM data was obtained from the "Amazonia" Information System (Alves et al. 1992), a remote sensing study that has been coordinated by INPE. The "Amazonia" System consists of a geographically referenced database of deforestation on the GIS extracted from Landsat imagery photographic products. Features like deforested areas (such as, cleared forest), forest, natural non-forest (or "cerrados"), and major water bodies, have been digitized to create 332 map sheets at the 1 250 000 scale, which cover the Legal Amazonia. The information of the five TM maps corresponding to the five AVHRR study areas was used as reference data. The remaining 11 areas shown in Fig. 1 could not be used because their analysis within the "Amazonia" Information System has not been completed yet.

The comparison between AVHRR and TM deforestation data was done in order to verify the AVHRR capability to detect changes in the Amazon forest. Initially, the geographical coordinates of the centers of 221 different sized polygons of deforested areas were located in the TM maps, with image dates varying from 24 July to 26 September 1990. These coordinates formed an information layer which was overlaid to the AVHRR resulting image in the GIS. Through visual analysis the number of correct locations of the TM centers of deforestation on the AVHRR images was determined. Next, the number of correct AVHRR locations was obtained just for the 50 polygons with deforestation larger than 3.1 km^2, out of the total 221 polygons.

Finally, an estimate of "false alarms" was obtained, based on areas where new deforestation was detected on the AVHRR resulting image but which could not be found on the TM maps. This was done by comparing the location of all polygons of new deforestation observed in the AVHRR resulting image in relation to the corresponding TM maps.

Results

Tables 1 and 2 show the results obtained from the visual analysis, where the coordinates of the centers of deforested areas located in the TM maps were overlaid on the AVHRR resulting image in the GIS. From the 221 new deforestation sites identified on the TM images, 125 (56.6%) were also detected by the AVHRR resulting image (see Table 1). In 68 cases (30.8%) the AVHRR product erroneously misclassified deforestation as original forest cover.

This misclassification of new deforestation as forest in the AVHRR resulting image can be interpreted as related to the size of the deforestation polygons in the TM maps. Many of these areas were relatively small, even smaller than the spatial resolution of the AVHRR (1.2 to 2 km^2, depending on the scan angle). Considering only the 50 TM deforestation polygons larger than 3.1 km^2, the rate of correct AVHRR deforestation identification rises to 90% (see Table 2).

Some TM polygons greater than 3.1 km^2 were not identified by the AVHRR, and this is explained due to the possible occurrence of selective deforestation in these polygons. In such cases a significant part of the forest is left standing up, and in the TM polygons just a minor change in the texture and color is noticed in relation to original forests. AVHRR, with its coarse resolution, did not indicate such subtle variations in the forest cover. Figure 4 shows a low altitude aerial view example of selective deforestation in the northeast of the study area, where narrow patches and a very small fire can be found; such minute features are not detectable with the resolution and orbit of the AVHRR.

FIG. 4—*Aerial view of selective deforestation in the northeast of the study area.*

Table 3 shows the results obtained from the analysis of "false alarms." Some of these false alarms, around 10%, occurred on areas of cerrado. Areas of this vegetation type are also subject to deforestation, but they were not analyzed in this work because of the lack of a TM reference base. Without these cases the percentage of false alarms is reduced from 32.4% to about 22%. Other factors also led to false alarms. These were misclassifications due to radiometric differences between AVHRR images, specially in the case of mixed spectral response of edge pixels lying along the contact between forest and non-forest areas [9], and to the misregistration of the AVHRR images caused by the maximum attainable accuracy of one pixel.

TABLE 1—*Results obtained from 221 polygons analyzed.*

TM/MAP Number	No. of TM Deforestation Polygons	Corresponding identification (classes) in the AVHRR image				
		New Deforestation	Regrowth	Forest	Non-Forest	Cloud
274	45	33	01	10	01	...
297	40	19	06	14	01	...
298	44	24	06	14	...	...
319	40	25	02	11	02	...
320	52	24	07	19	02	...
Total	221	125	22	68	06	...
%	100.00	56.6	09.9	30.8	02.7	...

TABLE 2—*Results obtained from 50 polygons greater than 3.1 km^2.*

TM/MAP Number	No. of TM Deforestation Polygons	Corresponding identification (classes) in the AVHRR image
		Correct AVHRR Location
274	09	09
297	07	07
298	07	07
319	10	10
320	17	12
Total	50	45
%	100.00	90.00

TABLE 3—*Total amount of new deforestation observed on AVHRR resulting image and percentage of "false alarms."*

Study area	AVHRR Resulting image	
	Total cases of Deforestation	"False alarms"
274	230	53
297	092	24
298	105	34
319	135	47
320	202	90
Total	764	248
%	100.00	32.4

Conclusion

This work is a pilot investigation of a low-cost methodology for a semi-automatic system to detect changes in the Amazon forest using multitemporal NOAA/AVHRR data and a GIS. The utility of channel 3 (~3.7 μm) AVHRR images was shown as an alarm tool to indicate areas suspected of new deforestation.

Results comparing deforestation on an AVHRR resulting image with corresponding high resolution Landsat-TM data indicated 56.6% of AVHRR correct location for 221 polygons of deforestation with different sizes, and 90% of correct location for 50 polygons with deforestation greater than 3.1 km². Considering the total amount of new deforestation polygons observed on the AVHRR resulting image, an error of about 22% of "false alarms" was verified.

The results have shown that NOAA/AVHRR has the potential to detect large deforestations in the Amazon forest much faster and cheaper than existing alternatives. Additional tests are being conducted to improve this methodology and to analyze the sources of errors towards an operational AVHRR deforestation detection program in Brazil.

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