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POTENTIALITIES AND LIMITS OF THE GOES-8 VISIBLE IMAGERY TO STUDY THE EFFECTIVE MAGNITUDE OF DEFORESTATION IN MATO-GROSSO, BRAZIL. A COMPARISON WITH NOAA-AVHRR MULTISPECTRAL DATA.

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Abstract. This paper presents the results of testing the potentialities and limits of the GOES-8 visible imagery to study the deforestation in Mato-Grosso, Brazil. The method has utilised data from the GOES-8 (Geostationary Operational Environmental Satellites) geostationary satellite and multispectral data from the AVHRR (Advanced Very High Resolution Radiometer) on the NOAA polar orbiters. The objectives of this study are to evaluate the spatial extent of this phenomenon on a regional scale and integrate the results in a GIS. The spatial resolution of the GOES-8 visible imagery (1 km) serves to monitor deforestation or more exactly to show the forest / non-forest differentiation on that scale. In most of the forested *municipios* the difference between NOAA and GOES calculated deforestation is less than 10%. However, in some complex landscapes where soil humidity is important, there is still some confusion in the GOES imagery.

Keywords: GOES-8, deforestation, Mato Grosso.

1. Introduction

The Amazonian forest is particularly concerned by an important deforestation and biomass burning in relation to the exploitation program, high population growth rate and rapid expansion of infrastructure such as roads. The results of various studies demonstrate that up to 10 % of the tropical Amazonian forest in Brazil has been cleared but in some areas (Rondônia, Para) the deforestation is more rapid: dos Passos (1998), INPE. Our field study is in one of the major regions concerned, the state of Mato-Grosso, Brazil situated between 7 and 18° S latitude and 50 and 62° W longitude: Dubreuil (2002).

Generaly, most of studies aimed at demonstrating the evolution of the land cover on a local or sub-regional scale using multispectral data from Landsat and Spot: Woodwell (1988), Skole, Tucker (1993). The high spatial resolution of these satellites makes these approaches possible because it provides synoptic views of large areas. But these studies did not provide any information on a global scale. One of our aims is to try and supply information on a regional and global scale. GOES-8 satellite, which offers a low spatial resolution (1 km) in the visible channel, is very effective in that perspective. While much research used multispectral data to create vegetation indexes, we tested the limits and potentialities of the GOES-8 visible imagery for monitoring the state of the forest cover taking Mato-Grosso as our example. A comparison of multispectral data from NOAA-AVHRR polar-orbiting meteorological satellite, which has a similar spatial resolution (1.1 km), with GOES-8 visible data could provide pertinent information. The final goal of this research is to provide a model according to the spectral irradiance of on-ground objects, highlighting the contrast between forest cover and non-forest cover in Mato-Grosso, Brazil.

2. GOES Principles

GOES-8 (Geosationary Operational Environmental Satellite) circles the Earth in a geosynchronous orbit, which means it orbits the equatorial plane of the Earth at a speed matching the Earth's rotation (15° of longitude per hour). This allows the satellite to hover continuously over one position on the surface. The geosynchronous spacecraft is about 35,800 km (22,300 miles) above the Earth, high enough to allow the satellite to record a full-disc view of the Earth. NASA launched the first GOES for NOAA in 1975 and the second one in 1977. Currently, the United States is operating GOES-8 (75°W), launched in 1994, and GOES-10 (135° E), launched in 1997. The last ones belong to the new generation of NOAA's geostationary platforms with better performances : five-band multispectral capability with high spatial resolution and 10 bit precision, higher quality imagery acquired more frequently (with routine 15 minute views of the United States), improved spatial resolution with better signal to noise imagery. As GOES-8 is a meteorological satellite, the satellite data are utilised for public, television and radio forecasts and weather advisory services. It is part of NOAA's operational weather satellite system that is composed of two types of satellites : geostationary satellites (GOES) and polar-orbiting satellites (NOAA-AVHRR). We should take into account that GOES was not initially meant to be a satellite programmed for land cover observations.

Observation is carried out by two instruments, the Imager and the Sounder. Only the first interests us in this study. The GOES-8 Imager is a five channel (1 visible, 4 infrared) imaging radiometer designed to sense radiant energy and reflected solar energy from sampled areas of the Earth's surface and atmosphere. The Imager's multispectral channels can simultaneously sweep an 8-kilometer north-to-south swath along an east-to-west path, at a rate of 20° (optical) east-to-west per second. The visible silicon detector array (channel 1 : 0.52-0.72 um) contains 8 detectors. Each detector produces an instantaneous geometric field of view (IGFOV) that is nominally 28 microradians (µrad) on a side. At the spacecraft's orbital point, on the surface of the Earth, 28 µrad corresponds to a square pixel that is 1 km on a side <http://ns.noaa.gov/NESDIS/>. GOES-8 is the first geostationary satellite to have such a good spatial resolution; although everyone is nowadays used to seeing global images of the Earth for weather forecasts (**Figure 1**), more details can be observed which are no longer of interest only for meteorologists.

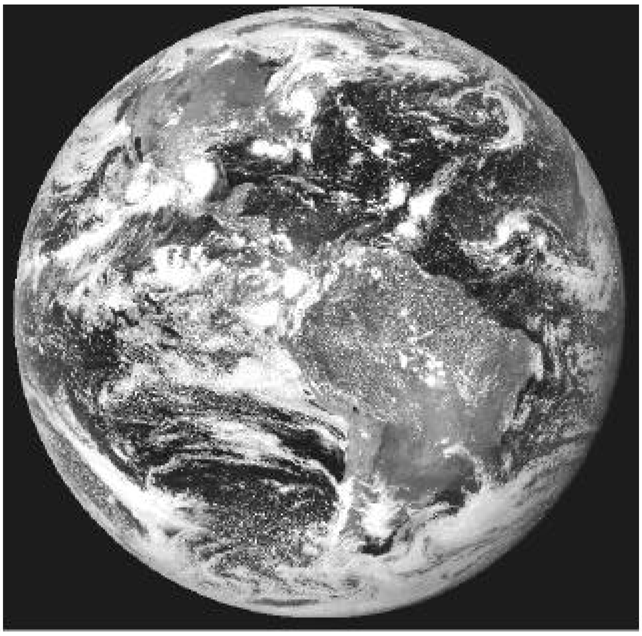

Figure 1: GOES image : full-disc

Full-disc view taken by GOES-8 (75°W) on 6th of september 1999, 18h00 GMT. High albedo values appear in white (clouds), low albedo values in black (oceans). Lands show various nuances of grey depending on land-cover, soil humidity, types of rocks...

The main advantage of geostationary satellites lies in the frequency of their imagery. A new full-disc view is available every 30 minutes. This temporal resolution is very useful when an area of the land cover is obscured by clouds or a plume produced by a fire located upwind : this is almost a common situation in the Amazonian forest. With this high frequency of images, it could take only a few hours or a few days to have this area cleared by looping a series of 30-minute images. For the moment, only the conterminous United States is covered by a low spatial resolution (1 km) and high temporal acquisition rate (one image every 15 minutes). This was conceived for the detection of atmospheric events such as fog, haze and pollution; the study of severe thunderstorms can also be detailed by this imagery. We will show that it could also be useful for other thematics and other areas in the world.

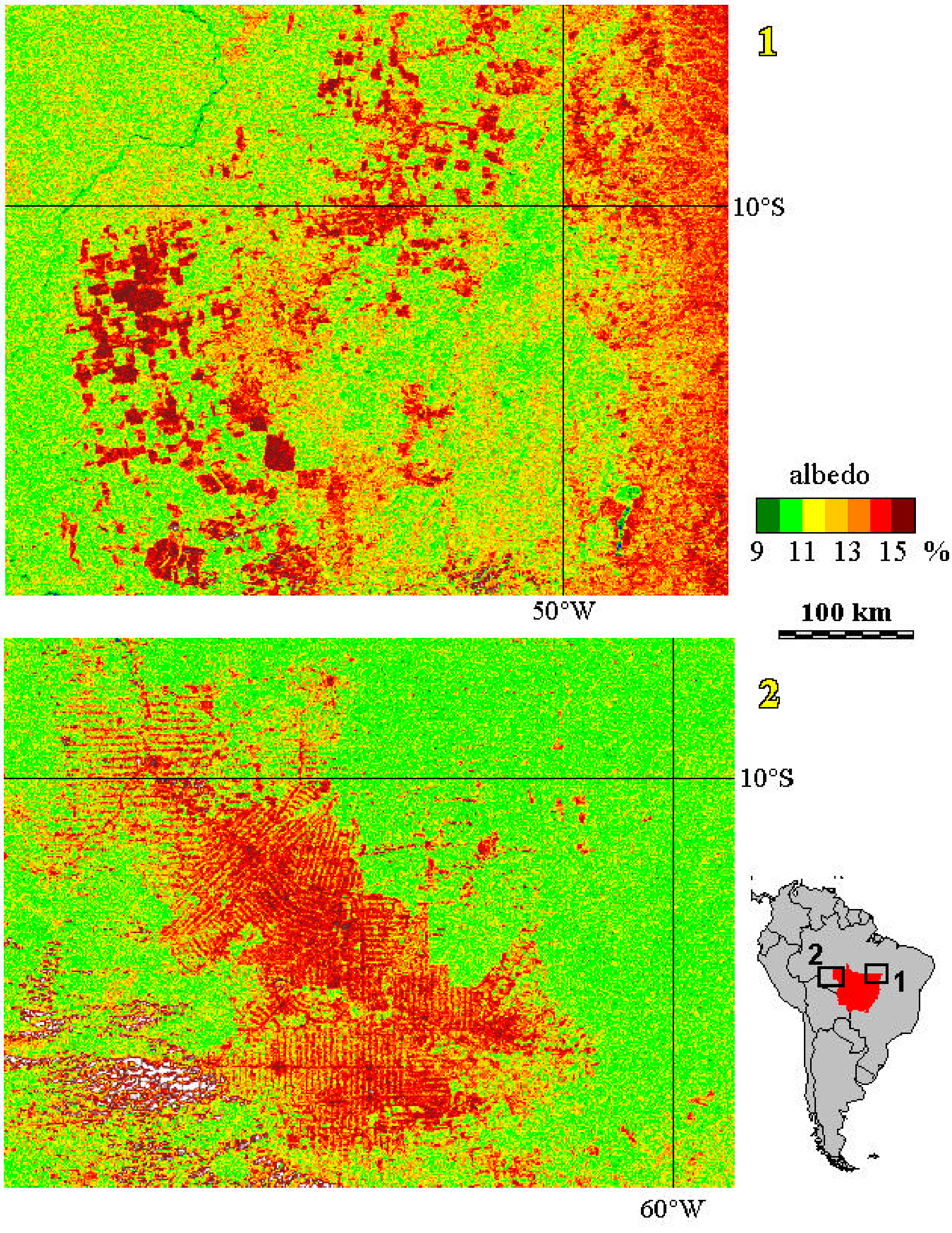

Figure 2 : Colour image GOES (11/07/1997): Para-Mato Grosso (1) / Rondonia (2)
Human settlements appear clearly using the full resolution (1km) of the GOES visible channel. Difference between small (100 hectares) plots of land in Rondonia and large clearings for cattle ranches in south Para is obvious.

Actually, a satellite with a high frequency of coverage and a relatively low spatial resolution like GOES-8 is very useful for a nearly-continuous monitoring of the land cover change process on a regional or global scale. In fact, for the first time, we can now observe the details of the forms of deforestation in Amazonia from a geostationary view-point. **Figure 2** shows the differences between forest clearing in Rondonia and at the frontier between Para and Mato-Grosso. In the first case, there are small plots of public colonisation by INCRA (Instituto Nacional de Colonizaçao e Reforma Agraria) leading to a typical spatial organisation of “fishbone patterns”. In the second, larger polygons correspond to cattle ranches, illustrating a private colonisation by wealthier families or commercial-scale operators: Engel (2000). The question is to see if those images can help us to quantify the deforestation rate and to monitor the tropical forest.

3. Images and procedures used

For this study, we use GOES-8 image of 11 July 1997 (**Figure 3**) and NOAA-AVHRR images of 10, 12 and 13 July 1997 (**Figure 4**). These scenes are clean, free of clouds, haze and smoke. We have GOES-8 visible data and NOAA-AVHRR multispectral data: channel 1 (visible), channel 2 (near infrared) and channel 3 (mid-infrared). Channel 3 , which includes the emitted signal and a very interesting small reflected component, enables us to take into consideration the effect of the atmospheric moisture and the smoke, which are very important in the tropics and can be very helpful in discriminating ground data: Malingreau, Tucker (1990). It is also of interest for fire monitoring in tropical regions especially in Amazonia: Di Maio Mantovani, Setzer (1997). The NOAA-AVHRR ang GOES-8 digital images are geometrically rectified according to a similar cartographic projection using a correction algorithm produced by the SATMOS `<http://www.satmos.meteo.fr/>`.

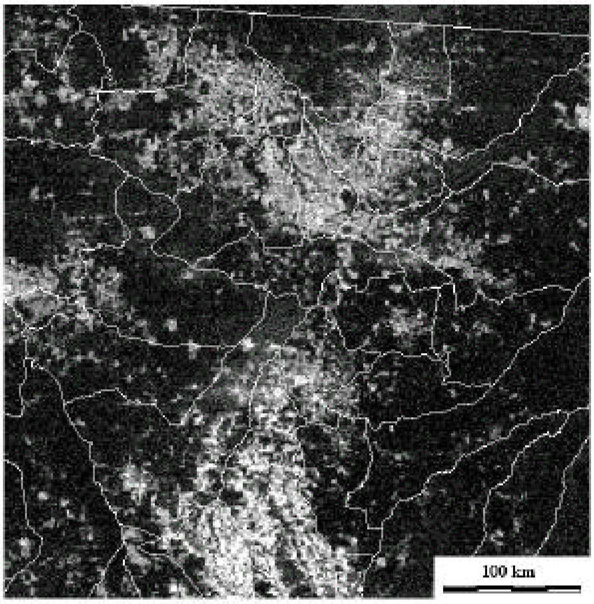

Figure 3 : GOES visible image : 11/7/97

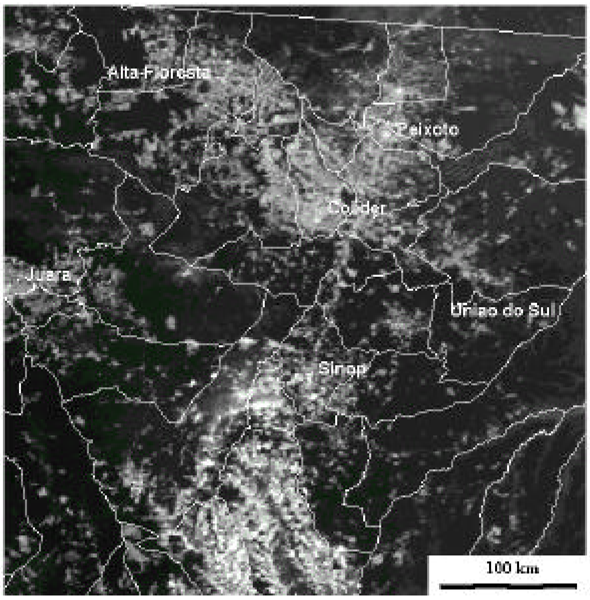

Figure 4 : NOAA image : 10/7/97

The limits of *municipios* are visualised in white. The high albedo values are represented in clear, the low albedo values in dark. The “stippled effect” of the GOES visible imagery can be easily noted.

Both images show extensive deforestation in north-central Mato-Grosso. The main towns are located on the road BR 163 (Cuiaba-Santarem) : Sinop is now a major town of about 100000 inhabitants, although it was only created in 1973. The name of Sinop is an acronym for the *"Sociedade Imobiliaria do NorOeste do Parana"*, which handled the colonisation in this area, developing mechanised crops (soy, maize). Further north, the other core (Alta Floresta, Colider, Peixoto) of colonisation is more diversified, with a mix of *garimpos*, cattle ranches and family smallholdings. Further inside the forest other small towns (Juara, Uniao do Sul) with associated deforestation areas appear, leading to an impression of a general nibbling away at the forest. So, such a diversity of landscape is ideal for a geographical study and the assessment of the potentialities of remote sensing methods.

During the first stage, the forest / non-forest differentiation has been made using the NOAA-AVHRR multispectral data. These data were processed to develop forest / non-forest rates using a two-stage cluster sampling technique. The first work consists in producing a colour composite image using channel 1 (visible), channel 2 (near-infrared) and channel 3 (mid-infrared). This often-used method clearly shows the diversity of landscapes in Mato-Grosso (**Figure 5**). Secondly, the NOAA-AVHRR image was classified using an unsupervised classification algorithm (IDRISI Cluster) and a post-regrouping of classes. The result is a 2 values image, where one value corresponds to the forest cover and the other to the "non-forest" cover. As we have little ground information at this scale, the forest / non-forest differentiation required subjective judgement especially in this region of high diversity of vegetation: RADAMBRASIL (1983), Rodriguez-Yi, Shimabuko, Rudorff (2000): however, the goal of our approach is not to validate or develop a new NOAA classification method but to compare simple results obtained with AVHRR datas with GOES visible datas.

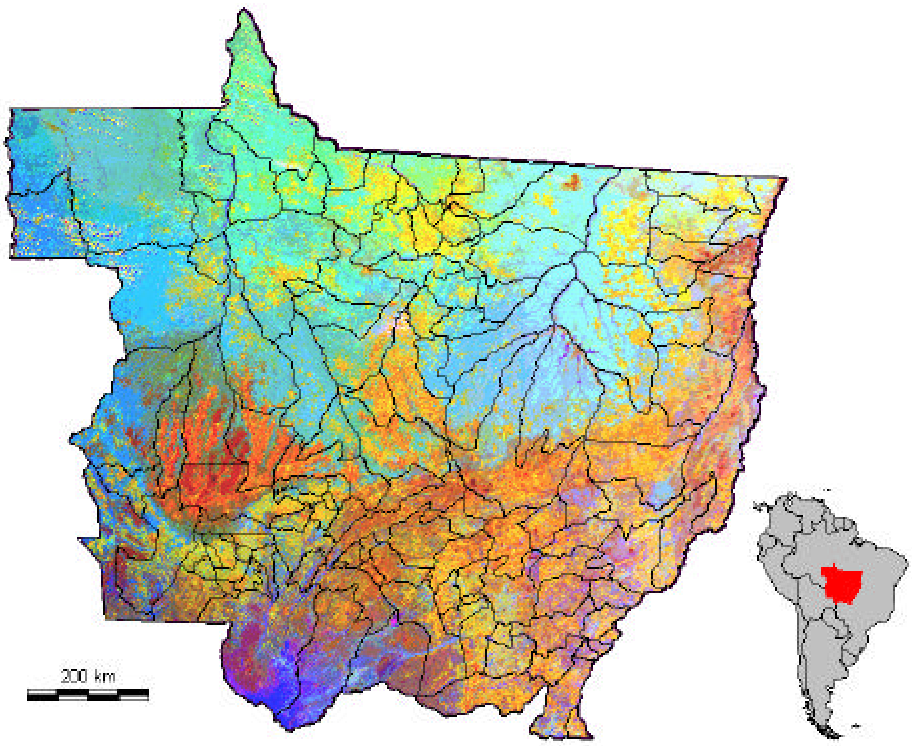

Figure 5 : Colour composite : NOAA 1,2,3 : 10/07/1997

The clear green and the clear blue region correspond to the undisturbed tropical moist forest cover. The orange and yellow regions correspond either to bare soils, culture or cerrados: according to us all these classes are non-forest cover. The dark blue regions correspond to the stretchs of water (the rivers).

The objective of this process is to create masks that can be superimposed on the GOES visible imagery in order to determine the albedo value that separates the distribution of the pixel values in accordance with the land cover. The difficulty is that certain albedo values fitted on to the forest cover areas are recorded in the clear land areas and inversely : this is due to the geometric correction of both the GOES and NOAA-AVHRR images and to the inherent mix of the pixels in GOES and AVHRR imagery: Lucas (1996). A simple method has been utilised to resolve this issue: we calculate a percentage for each GOES albedo value in relation to its presence in forest area or non-forest area (**Figure 6**). We estimate that the presence of 50% of an albedo value in an area represents and belongs to this area. So, the albedo value of the GOES visible imagery, which corresponds to a rupture in the type of land cover is 12.2. In other words, this means that pixels that have an albedo higher than 12.2% correspond to non-forest and those with less than 12.2% are forested ones. Now, we can execute a density slicing which involves the grouping of image areas with similar digital number to show the opposition between the forest cover and the non-forest cover in Mato-Grosso (**Figure 7**).

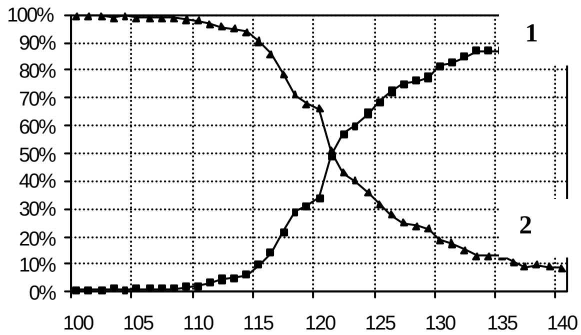

Figure 6 : Graph of albedo frequences

Percentage of each GOES albedo value in relation to its presence in forest cover (1) and in non-forest cover (2). The GOES albedo 12.2 represents the division value of forest/non-forest differentiation in GOES visible imagery.
y-axis : Percentage of presence in each cover
x-axis : GOES albedo value * 10.
1:presence of GOES albedo value in forest cover.
2:presence of GOES albedo value in non-forest cover.

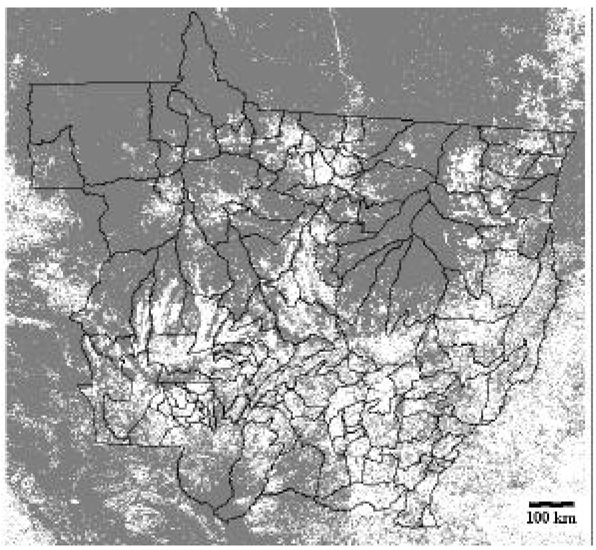

Figure 7 : Density slicing GOES : forest / non-forest

Forest/non-forest differentiation using a density slicing of GOES visible imagery on 11 July 1997. In grey, we note the forest cover (albedo less than 12.2%); in white the non-forest cover (albedo more than 12.2%). In black are represented the limits of the *municipios* in Mato-Grosso.

4. Results

The interest of such a study is to integrate as soon as possible new information on deforestation in a GIS. The greatest care must be taken because of the issue of the spatial resolution variation (1 km for GOES, 1.1 km for NOAA) and the geographical projection. So, in both cases, we calculate the percentage of forest cover by "*municipio*". As those spatial entities are about 5000 km², the spatial resolution of one kilometre of GOES visible channel is interesting in that way. The problem is that, the number of *municipios* increase as the population grows and the occupation of space becomes more intensive. For example, there were only 38 *municipios* in 1980 for 1.1 million inhabitants in Mato-Grosso and 128 in 1998 for 2.3 million inhabitants (dos Passos, 1998). The size of the *municipios* gives also a good idea of human density, showing a major opposition between the North (large *municipios* and few people) and the Southern "historical" part of the State. We chose to estimate the percentages using the map of administrative entities of 1998 (INPE).

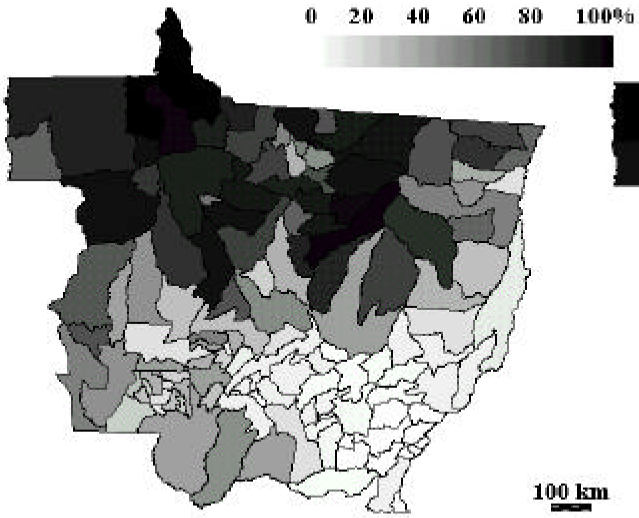

Figure 8 : Forest cover using NOAA

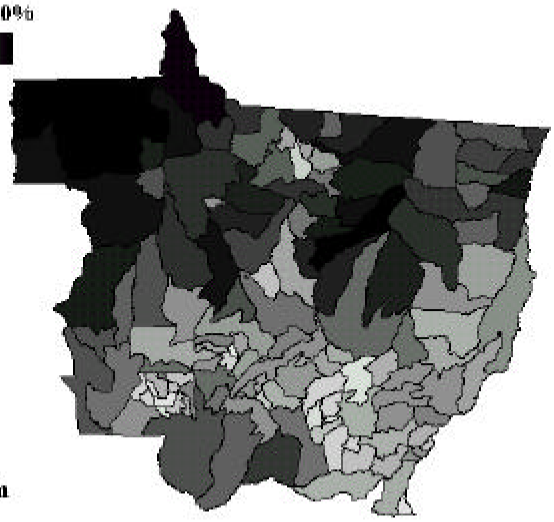

Figure 9 : Forest cover using GOES

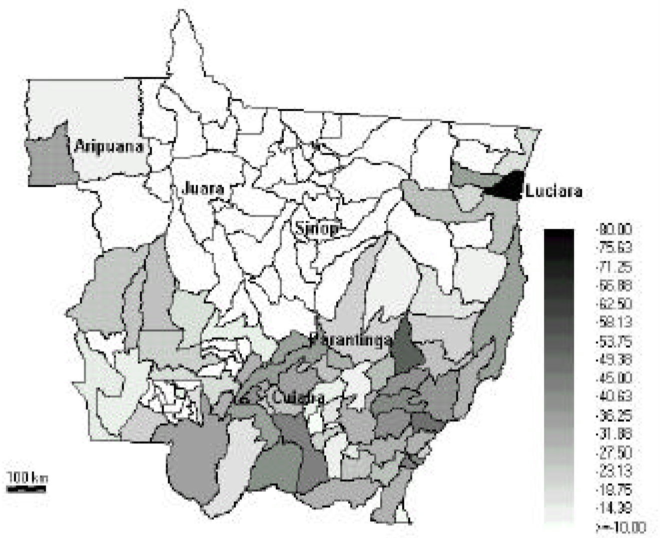

Figure 10 : Map of difference of forest cover NOAA – GOES: 1997

Variation (in %) between the NOAA-AVHRR forest cover estimation and the GOES forest cover estimation by *municipio* in Mato-Grosso.

Figures 8 and 9 show the good relation between the two estimations. The opposition between the northern part of the state (more than 50% of forest cover) and the southern part is obvious. The deforestation which occurs mainly in the central part of Mato-Grosso by the roadsides of BR-163 is also clear on both images. For a better understanding, we calculate the difference between the two estimations (NOAA-GOES). **Figure 10** shows that generally in the forest area there are less than 10% of difference (all *municipios* in white on the map). The exceptions appear in northwestern Mato-Grosso (Aripuana) due to the presence of clouds on the images, and in the eastern part of the State. The case of Luciara, *municipio* where the difference reaches 80% requires an explanation : in this part of the state, the landscape is mainly composed of flooded cerrados belonging to the Araguaia system (the same observations can be made with the Pantanal system in the South). Though, the albedo values measured by GOES are high whereas for the NOAA estimation, we classify this class in non-forest cover (**Figure 5**). Other *municipios* surrounding Luciara are more forested and so the GOES estimation agrees better with the NOAA one. Intermediate values of difference (10 to 30%) are frequently found in the central part of the state because the *municipios* are just at the limit between forest and cerrados (Paranatinga for example). The main differences occur in the south-east where forest is replaced by cerrados due to climatic conditions. The method, utilised to estimate forest cover, gives bad results in this area because there are still low albedo values observed by GOES whereas it is much easier on NOAA classification to discriminate this type of landscape. However, as our main goal was to estimate the deforestation, those results in a non-forested area are not really a problem.

5. Conclusion

This research demonstrates the capacity of the GOES visible imagery to demonstrate the issue of deforestation. The separation value we found (12.2%) between forest and non-forest landscapes in Mato Grosso can be considered as a reference value. The spatial resolution of GOES visible imagery provides pertinent information on a regional and global scale and gives a great synoptic view of the disturbed forest area. This is an advantage in comparison to polar-orbiting satellites such as Landsat TM or SPOT but this spatial resolution (1 km) and the lack of near infrared informations introduce some queries about the effective content and the mix of the pixels.

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