LARGE-SCALE MONITORING OF FOREST DISTURBANCES IN NORTHERN MATO GROSSO FROM 2000 – 2011 BASED ON THE CLOUD COMPUTED ΔRNBR INDEX

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ABSTRACT

This paper describes a novel approach of large-scale remote sensing - based monitoring of human-induced forest disturbances by selective logging and forest fires for the years 2000–2011 in Northern Mato Grosso State in the Brazilian Amazon, comprising more than 414,000 km^2. A pixel-based yearly change detection approach is applied on multiple Landsat imagery, using a self-referenced Normalized Burn Ratio (ΔrNBR) index through cloud computing with Google Earth Engine. Assessed within grid cells of 300 m ×300 m spatial resolution, the overall area of disturbed forest over 12 years covers 53,302 km^2 (24,1%), thereof 38,255 km^2 by selective logging (17,3%) and 18,711 km^2 (8,4%) by forest fires, including 3,664 km^2 (1.7%) in both categories. The yearly areas under selective logging and affected by forest fire range from 1,819 km^2 (2009) to 6,984 km^2 (2005) and from 68,0 km^2 (2001) and 10,258 km^2 (2007), respectively.

Key words — forest disturbance, remote sensing, REDD+, Brazilian Amazon, selective logging, forest fires, ΔrNBR.

1. INTRODUCTION

Disturbances within tropical forests are a major source of carbon emissions in tropical and subtropical latitudes [1,2]. They can lead to a degradation of the forests and to severe consequences for biodiversity and ecosystem services [3]. The main causes of forest disturbances in the Brazilian Amazon are unsustainable selective logging and forest fires. It is indispensable to know where and how forest cover changes are happening, as it allows for tackling the problem, supporting planning, protective measures and proposing reduction targets, especially within the context of incentive mechanisms such as REDD+ (Reduction of Emissions from Deforestation and Forest Degradation) [4].

Efforts have been made to map and quantify the extent of forest disturbances, however, compared to the consolidated methods of remote sensing – based monitoring of tropical deforestation [5,6,7], the large-scale detection of forest degradation with satellite imagery still remains a challenge [8]. The reason for this lies e.g. in the highly dynamic spatial–temporal patterns of forest disturbance events, which can be detected by remote sensing only for a limited amount of time due to rapid vegetation regrowth [4].

Various studies have tackled the problem through visual interpretation, like INPE's DEGRAD project [7], or by single image or time series analysis of fractional images [8,9,10]. As a novel approach, we propose a cloud computing analysis of the Google Landsat archive with Google Earth Engine (GEE) [11], using a self-referenced Normalized Burn Ratio (NBR) index: the ΔrNBR index as proposed by [12].

2. MATERIAL AND METHODS

2.1. Area of Interest

As area of interest we have chosen Northern Mato Grosso, defined as intersection between Mato Grosso State at the Southern border of the Brazilian Amazon, and the Brazilian Amazon biome [13], an area with an extent of ca. 1,250 km in E-W and 700 km in N-S direction, covering an area of approximately 414,000 km^2 (Figure 1).

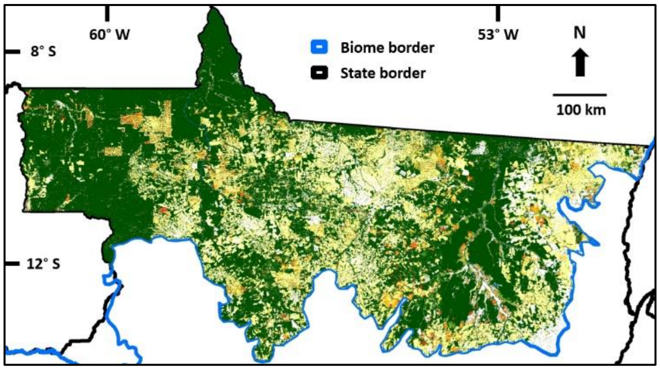

Figure 1. Study area: Northern Mato Grosso

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Mato Grosso State is a hotspot of forest cover change, i.e. deforestation, selective logging and forest fires [4,7]. The area of interest is covered by (parts of) 26 Landsat path/row scenes, leading to an analysis of ca. 520 satellite images per yearly change detection.

2.2. ΔrNBR index calculation

The ΔrNBR index generates the difference between the composites of two reference periods. The methodology produces seamless and consistent maps, highlighting patterns of canopy disturbances (e.g., encroachment, forest fire, selective logging), and keeping artifacts at minimum level [12].

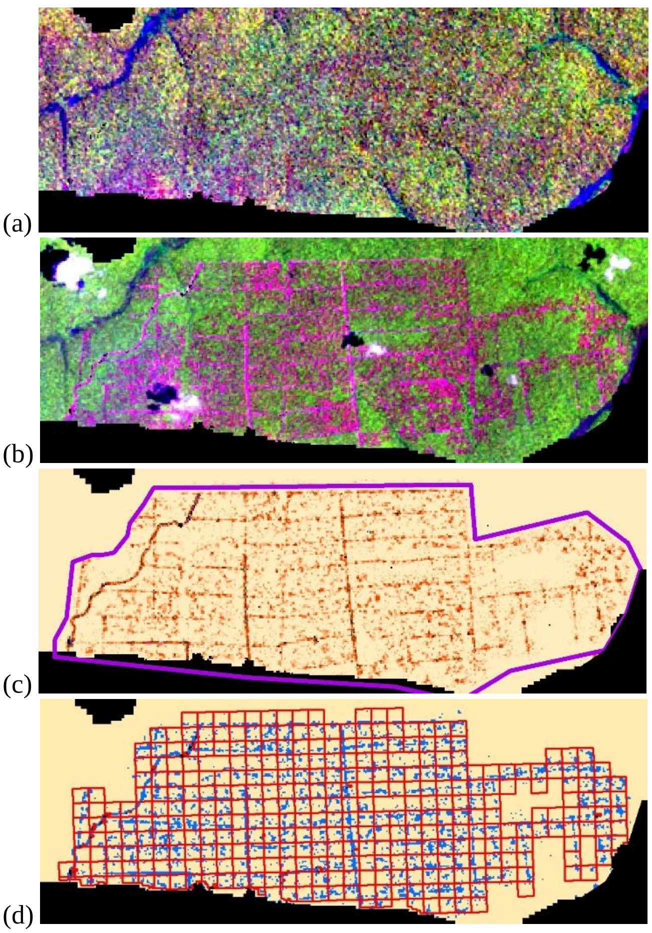

Figure 2. a) Exemplary single satellite image before (2009) and b) after forest disturbance event (2010), c) ΔrNBR result with 'positive mapping' in purple, d) ΔrNBR with applied threshold and 300 m X 300 m grid overlay (disturbed forest only) – forest mask in black

In our study, the ΔrNBR was cloud-computed with GEE as a yearly change detection approach with a year n as reference year and year n+1 as year of forest disturbance events to be detected (Figure 2). The overall time period of yearly assessments ranges from year 2000 until 2011.

2.3. 'Positive mapping', threshold and grid approach

The yearly ΔrNBR index results underwent a so-called 'positive mapping' (Figure 2c), by visual interpretation, in order to exclude false detections, due to e.g. incorrect cloud masks, inter-annual vegetation changes in savanna areas, water level changes along river courses or image artefacts, from further processing. At the same time, the forest disturbances were separated according to their cause, forest fire or selective logging.

A threshold was applied to the 'clean' ΔrNBR index data, defined by [14], in order to produce binary pixel-based maps of forest disturbances.

As last step, a 300 m × 300 m grid was superimposed on the binary maps, counting the number of disturbance pixels for each grid cell. This last step, following the approach of [4], ensures the geographic consistency of the analysis over time. The grid size follows the recommendation of [15].

2.4. Forest mask

The previously described process was applied to areas that were defined as forest from a specific forest mask, based on a combination of PRODES deforestation map [16], status year 2016, and the Roadless Forest map by [17], status year 2000, which was used to exclude smaller areas of savanna, rock outcrops, small roads and small watercourses from analysis. Our approach thus mapped the history of forest disturbances of the forest cover in 2016, to avoid double accounting in the context of the REDD+ mechanism.

3. RESULTS

The map of forest, status 2016, covered 221,573 km^2, or 53,6% of the whole area of Northern Mato Grosso. Between 2000 and 2011, 38,255 km^2 of forest were mapped as selectively logged, adding up to 17,3% of the 2016 forest cover. For the same period, 18,711 km^2 of forest (status 2016) were burned (8,4%) (Figure 3).

The yearly statistics of forest disturbances shows that the area of deforestation [16] is surpassed by the selective logging area in 2007. This comparison, however, can only be approximate, as the two forest masks (this study and PRODES) differ slightly. The yearly areas of burned forests show the known peaks of 2007 and 2010 [18] (Figure 4).

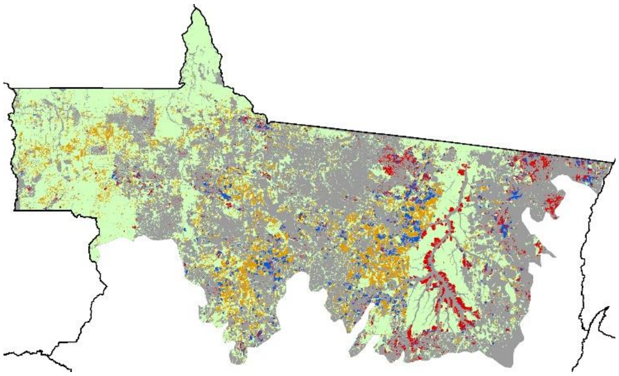

Figure 3. Area of selective logging (orange), forest fire (red), and areas of both disturbances (blue) from 2000-2011, light green: forest 2016, grey: non-forest 2016

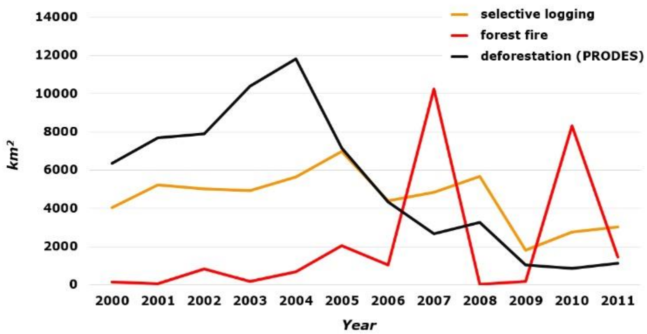

Figure 4. Yearly areas of selective logging (orange), forest fires (red), and deforestation (black) from 2000-2011

Three municipalities across Northern Mato Grosso were selected, namely Colniza, Juara and União do Sul, to examine the yearly areas under selective logging from 2000-2011 in different regions (Figures 5, 6, 7). The three selected municipalities differ considerably with respect to geographic position, size, forested area and area of selected logging (with respect to the 2016 forest mask) (Figure 5,6).

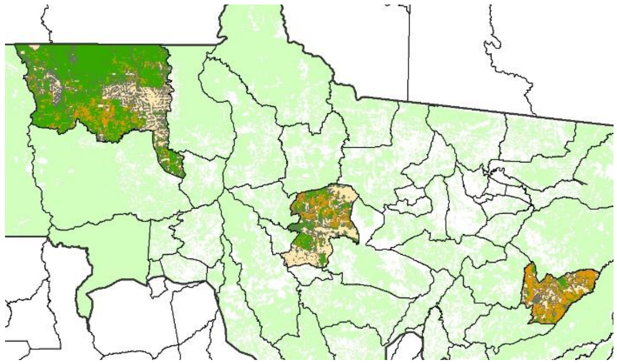

Figure 5. Geographic position of Colniza, Juara and União do Sul municipalities (from West to East), forest 2016 in green, selective logging areas in orange)

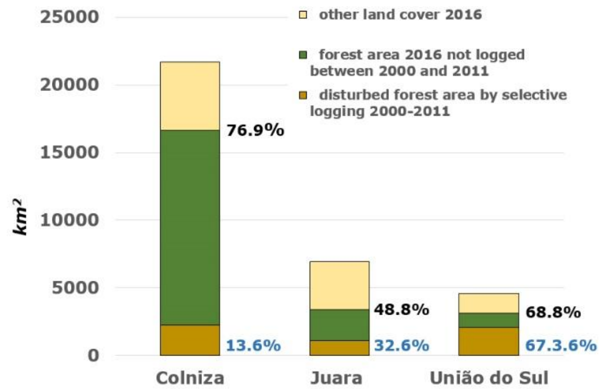

Figure 6. Municipality size, forest cover 2016 and accumulated areas of selective logging 2000-2011 (indicated in blue as % of forest cover) for Colniza, Juara and União do Sul

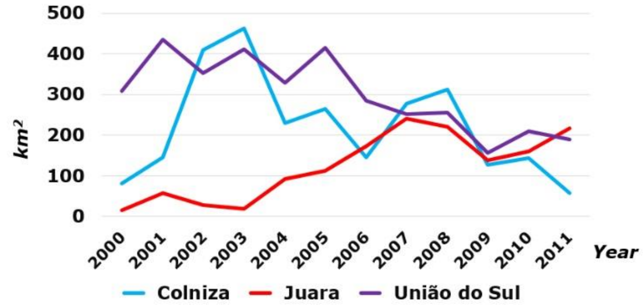

Figure 7. Areas of yearly selective logging 2000-2011 for Colniza, Juara and União do Sul

The yearly amount of selectively logged forest shows very different trends (Figure 7). While areas under selective logging decrease in the course of the 12 years for União do Sul, the municipality of Juara shows an increasing trend, whereas Colniza shows high variation with an overall trend of decrease.

4. DISCUSSION

The ΔrNBR index approach, as it is, is designed for detecting forest disturbances in evergreen tropical forest. It is not (yet) possible to work e.g. on savanna forest or deciduous forest, as the inter-annual changes are not taken into consideration by the code at present. A time-series analysis component would have to be integrated into the process for this purpose.

Depending on the area, some commission errors still occur, mainly caused by cloud cover, phenology, image artifacts, and changing water levels and vegetation changes along river courses. By ‘positive mapping’, we avoided these errors in our statistics. ‘Positive mapping’ does not take up much time, due to the valuable ΔrNBR index input, where patterns of selective logging and forest fire can easily be separated from false detections.

The next steps would be to put in place a throughout accuracy assessment in order to evaluate in-depth the quality of the results and to relate carbon emission to the mapped areas of forest fire and selective logging for REDD+ reporting.

The usage of cloud computing provides new possibilities for remote sensing analysis. The outsourcing of image archive and computing capacity enables a fast image analysis and a quick adaption of the used code. In consequence, an enlargement of the area of interest or an extension of the analyzed period is feasible.

5. CONCLUSIONS

The ΔrNBR index approach, based on cloud computing, is a novel, robust and fast way of mapping yearly forest disturbances in evergreen forest through change detection. It can be an important component for the future Brazilian REDD+ reporting on forest degradation.

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