REASONING ABOUT DEFORESTATION TRAJECTORIES IN PARÁ STATE, BRAZIL

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ABSTRACT

The Brazilian Amazon biome comprises the greatest rainforest in the world with an abundant density of biodiversity. In the last years, this biome has been subject to an extensive removing of forested areas mainly due to the expansion of agriculture and pasture for cattle ranching areas through of the selective logging and forest fires. This paper uses a spatiotemporal interval logic mechanism extended from Allen's interval temporal logic to reason about deforestation. We show that this method is a tool to help scientists and policymakers to extract relevant information about land-use change. Using the interval-based approach interesting questions are translated into an expression that can be machine interpreted. In this work, we show how to identify and quantify land-use transitions in Pará State, in Brazil, from the deforestation data from 2007 to 2017 produced by the PRODES project.

Key words – *Spatiotemporal, PRODES, land-use change, trajectories, deforestation*

1. INTRODUCTION

In the last decade, satellite imagery to observe the Earth became ubiquitous and the technology to handle these big data sets is accessible. This has lead to an unprecedented generation of data about the cover and the use of land at regional [1], national [2] and global scale [3].

In this work we are interested in studying the unique Amazon biome in Brazil, an invaluable environmental asset to Brazil and to the world. In Brazil, the Amazon forest preservation and the reduction of deforestation, has been considered a priority by the government, the civil society, and environmental organisations. This task demands efforts for effective monitoring and control, including protective laws for fighting illegal deforestation. The Brazilian Legal Amazon (BLA) is an area of 5.2 millions km^2 accounting for 64% of the Brazilian territory. The Project for the Estimation of Deforestation in the Brazilian Amazon (PRODES), conducted by the National Institute for Space Research (INPE) has been producing annual deforestation maps for the BLA since 1988 [1]. The yearly PRODES deforestation data covers the period from August of the previous year to July and is generated from the interpretation of medium resolution images (from Landsat, CBERS and other missions) wall-to-wall for the entire BLA.

PRODES data is available to the scientific community and the society following an open access policy, and it is considered the best source of information about deforestation in Amazon. The correlation between deforestation rates (Figure 1) in BLA and factors such as the agriculture expansion, the intervention in food supply chains can be observed [4].

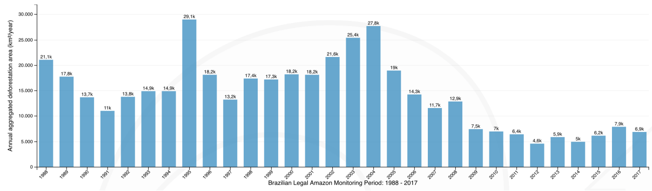

Figure 1: Deforestation increments measured by PRODES. Source: INPE (2017) [1].

This work aims to contribute with studies about deforestation processes by presenting a tool to spatially reason about land-use changes using the concept of trajectories.

1.1. Land-Use Trajectories

The ability to observe a single point in space a long time consistently allows the identification of a spatiotemporal features of land, and represent its trajectories of change, which reveal relevant information about the processes occurring at that point. We consider a *transition*, in a given spatial unit of observation (e.g. a pixel), the observed change from one land-use class to another; for example, when a forested area is converted to pasture. We consider a *trajectory* as a sequence of transitions observed during a period of time [5]. For example, during five temporal observations of an area, one found it to be, respectively, a forest in the first year, it remains a forest in the second year, than it became a pasture in the third year, and finally became a cropland area during the next two years. We represent this trajectory as *forest* → *forest* → *pasture* → *cropland* → *cropland*, where we observe four transitions during the studied period. Transitions do not follow fixed patterns, resulting in a great variability of trajectories, especially when observing large areas during long periods of time [6].

In this work we explore the subset of PRODES data restricted to an area of Pará State in Brazil. This paper is based on earlier results published in [7–9] obtained in the context of the e-Sensing Project [10]. This paper is organised as follows. In Section 2 we describe the materials and methods used in this work. In Section 3 we present two case studies related to the deforestation process. Finally, Section 4 concludes the paper.

2. MATERIALS AND METHODS

2.1. Study Area

The study area in located in the southwest part of the Pará State (PA), Brazil, within the BLA, which is covered by the Landsat scene identified by path 227 and row 65. It covers part of the municipalities of Itaituba, Novo Progresso and Altamira (see Figure 2). In recent years this area has been subject to an extensive removing of forested areas [11, 12].

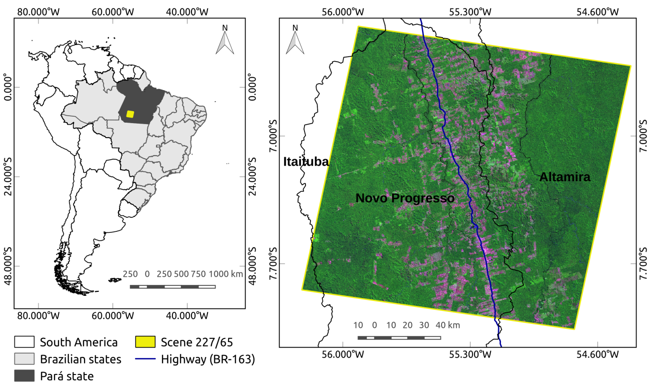

Figure 2: The study area, Landsat scene path 227 and row 65, within Pará State, Brazil.

2.2. Data Description and Pre-Processing

The input data is composed for a set of images derived from PRODES data, in shapefile format. The PRODES data includes polygons with thematic classes which discriminate annual classes from 2007 to 2017. Originally, the PRODES data include six classes: Forest, Deforestation, Non-forest, Hydrograph, Clouds and Residue (deforestation not detected, but occurred in previous years). For building the input data, with a set of images from 2007 to 2017 with deforestation trajectories, from PRODES shapefile data, we grouped the six classes in four classes, such as Forest, Deforestation, Non-Forest, and Hydrograph, where we performed:

i) the Residue class was grouped as Deforestation and associated to the previous year, and class Clouds do not consider.

ii) to separate by year, to build the land-use trajectories previous, we create new columns in the attribute table of the PRODES shapefile for each year from 2007 to 2017. Then, we grouped the Deforestation classes detected in the year as Forest in the previous year. For instance, is Deforestation 2017, then this area was Forest in 2016.

iii) we rasterise the PRODES shapefile data by each year and we create annual images from 2007 to 2017, in a regular partition with a spatial resolution of 60 meters. This stage generated a set of 11 images with deforestation trajectories (Figure 4).

2.3. The LUC Calculus Formalism

The formalism for reasoning about land-use change trajectories, called *LUC Calculus* for short, has been discussed in previous work [9]. In this subsection, we will describe it.

In this work, we consider that an interval-based approach is more suited to represent land-use change trajectories because changes in land-use demand a time to occur, are not instantaneous. For example, the deforestation of a large area of forest to the production of large-scale agriculture requires time and significant financial resources for implementing and support. These considerations led us to adopt Allen's interval temporal logic as one of the basic components of LUC Calculus [13].

In the LUC Calculus we have extended Allen's proposal to spatial locations as part of a more general framework for reasoning about land-use change [14]. Each image can be thought of a set of locations (pixels) whose values describe the state of the study area at a given time. Our spatial locations correspond to pixels in remote sensing images. Therefore, the locations do not change, but the state of each location does. The building blocks of the formalism are:

1. a set of spatial locations ($L = l_1, l_2, ..., l_n$);
2. a set of classes ($C = c_1, c_2, ..., c_n$), typical land-use classes, e.g., $C = (Forest, Pasture, Soybean)$;
3. a set of non-overlapping and sequential time intervals ($T = t_1, t_2, ..., t_n$);
4. a set of temporal predicates defined by Allen [14];
5. a set of predicates for one interval and multi-interval comparison:
   - $HOLDS(l, c, t)$: which evaluates as true when a land-use class c holds during the interval t;
   - $RECUR(l, c, t_i, t_j)$: which evaluates as true when a location holds a land-use class c during two non-continuous distinct intervals t_i and t_j;
   - $CONVERT(l, c_i, t_i, c_j, t_j)$: which evaluates as true when a location holds the land-use class c_i during the interval t_i, land-use class c_j during the interval t_j and t_j is sequential of t_i;
   - $EVOLVE(l, c_i, t_i, c_j, t_j)$: which evaluates as true when a location holds the land-use class c_i during the interval t_i, land-use class c_j during the interval t_j and t_j is not necessarily sequential of t_i.

Figure 3 illustrates the deforestation trajectory for a location l_1 from 2001 to 2005, considering one observation per year: is a forest (F) from 2001 to 2002, and a deforestation (D) area from 2003 onward.

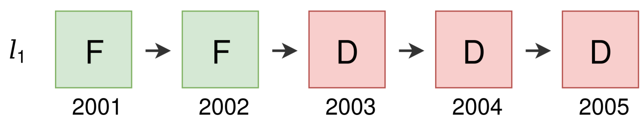

Figure 3: Example of a deforestation trajectory in a single location.

With the application of the LUC Calculus is possible to formally express interesting queries for land-use change

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Figure 4: Scenes study area.

analysis and better explain what happened over a particular study area. This formalism was implemented in a R programming language.

3. RESULTS AND DISCUSSION

In this section, we show two examples of application using LUC Calculus to reason about deforestation trajectories.

3.1. Deforestation Expansion

To single out about deforestation increasing in the study area, we use the whole history of the area as a set of deforestation trajectories. For instance, an area was forest from 2007 to 2010, later converted to deforestation from 2011 to 2017. For reasoning about deforestation expansion, we apply the HOLDS predicate to identify only Deforestation class that holds from 2007 to 2017. Table 1 shows a simple logical expression used to uncover areas of deforestation.

Table 1: LUC Calculus expression to identify deforestation holds from 2007 to 2017.

Search for all 'Deforestation' class that HOLDS over the years since 2007
$\forall\, l \in L, \forall\, t_i = [2007 : 2017] \in T,$
$HOLDS(l, "Deforestation", t_i)$

Figure 5 presents the total area of deforestation since 2007, we can quantify the evolution of forest loss areas during the study period. The result shows that a significant portion of the forest was deforested, around 1800 km^2 of difference between 2007 and 2017. Studies show that selective logging was the most important cause of forest degradation [11].

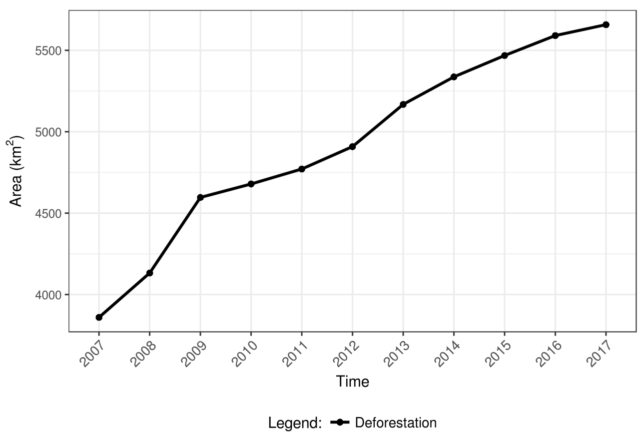

Figure 5: Total of Deforestation class from 2007 to 2017.

To verify the evolution of Deforestation class over Forest areas in 2007, we apply the EVOLVE predicate. Table 2 shows the LUC Calculus expression to represent this evolution. Figure 6 presents the total of deforestation class that evolved from forest areas in 2007. The largest increase was in 2009 with around 736 km^2 of deforestation in relation

2008 with 272 km^2. Between 2008 and 2017 the growth rate of deforestation increased 559,11%. This result shows the impact of deforestation over forest over time, with over 1700 km^2 of deforestation class has evolved from forest areas in 2007.

Table 2: LUC Calculus expression using EVOLVE predicate.

Search for all forest areas that have been replaced by deforestation from 2008.
$\forall\, l \in L, t_1 = [2007, 2008], \forall\, t_i \in T, t_i \neq t_1,$
$EVOLVE(l, \text{“}Deforestation\text{”}, t_1, \text{“}Forest\text{”}, t_i)$

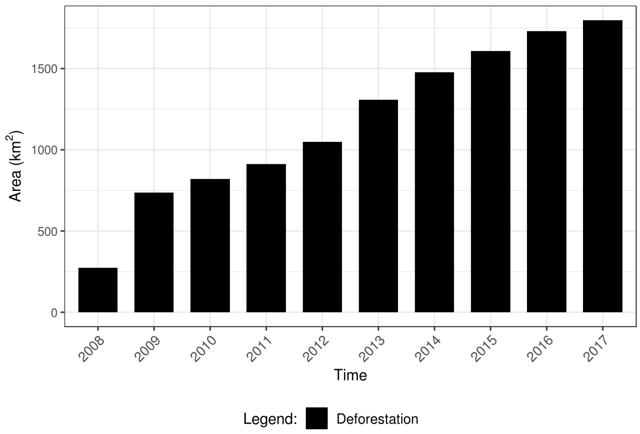

Figure 6: Total area of deforestation that have been evolved from forest 2008 to 2017.

This study shows the potential contribution of the LUC Calculus application to better understand studies of land-use and land-cover dynamics using remote sensing satellite data.

4. FINAL REMARKS

This paper shows two applications using the spatiotemporal interval logic mechanism, LUC Calculus, for reasoning about deforestation trajectories in a particular region of Pará State from 2007 to 2017. We consider that the application of the LUC Calculus in this work contributes as a tool to formally express and write research questions about particular transitions and quantify results or highlight scenarios.

The results showed that the deforestation continued to increase over time, and the use of different analysis method is important to study the impact of forest loss. This kind of information is essential to detect and map deforested areas.

The LUC Calculus was implemented in R, an open source programming language and a statistical environment with a wide variety of source statistical and graphical packages. The implementation is available at <https://github.com/e-sensing/lucCalculus>.

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